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wards let them be put together, and the process of magnetizing be performed repeatedly upon each by the rest; and it will be found that each magnet possesses nearly, if not quite as much magnetism as the one employed in the first instance, that is, as the prime motor itself. This fact can scarcely be doubted, although it is at variance with the Newtonian law of the perfect equality of action and reaction as applied to mechanical forces, as no force can be supposed capable of generating under the same circumstances a force greater than itself.

Again, suppose we consider caloric as a moving force; what relation is there between that which is required to ignite a quantity of gunpowder and the caloric developed by its combustion? Several similar instances might be adduced of the inapplicability of the Newtonian law to the explanation of obscure physical facts.

LXXXVIII. *On a new Galvanic Battery.* By the Rev. N. J. Callan, *Professor of Natural Philosophy in the College of Maynooth.**

The following paper describes a new galvanic battery, consisting of 20 zinc and as many double copper plates, the whole of which may, by substituting one mercury trough for another, be made to act as a single pair of plates, or as 2, 3, 4, 5, 6, 10, or 20 voltaic circles; and which is capable of producing, by the aid of an electro-magnet, a voltaic current equal in intensity to that of a battery containing 1000 pairs of zinc and copper plates.

Under my directions, and on a plan suggested by me, a very large galvanic battery has been lately constructed for the College of Maynooth. This battery consists of 20 zinc plates, each two feet long and two feet broad, and of as many copper cells, each sufficiently large to contain one of the zinc plates. To each zinc plate is soldered a copper wire about half an inch thick and six inches long. The wire projects from the plate in a direction nearly parallel to the sides, and nearly perpendicular to the edge of the plate, which is vertical when the plate is in its copper cell. At two inches from its extremity the wire is bent so as to form nearly a right angle at the bend, and so that these two inches are parallel to the vertical edge of the plate. A wire of the same thickness, and about two inches shorter, is soldered to each of the copper cells: it is bent in the same way as the wires belonging to the zinc plates.

* Communicated by the Author.

Figures 1 and 2 represent a zinc plate and a copper cell along with the wires soldered to them. The 20 copper cells are put into a wooden box about 3½ feet long, 2 feet 2 inches deep, and nearly 3 feet wide, and are separated from each other by partitions of wood. The 20 zinc plates are let down into the copper cells, and are lifted up, at pleasure, by means of a windlass. To prevent the contact of the zinc plates with the copper cells, each zinc plate is covered with a woven net of hemp. When the 20 copper cells are in the wooden box, and the 20 zinc plates in the copper cells, the wires soldered to the copper cells project about ¾ of an inch from one of the sides of the box, and their extremities descend nearly 2 inches below the upper edge of the same side: but the wires soldered to the zinc plates project nearly 2 inches from the same side of the box, and their extremities descend as low as the extremities of the wires belonging to the copper cells. Thus, if A B (fig. 3.) in the exterior surface of one of

Fig. 1.

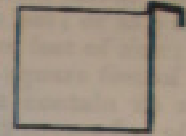


Fig. 2.

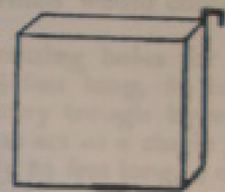
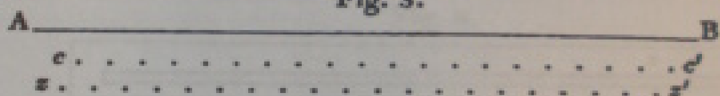


Fig. 3.



the sides of the box be parallel to the upper edge of the same side, and nearly 2 inches below it, then the row of points *c c'* will represent the extremities of the wires belonging to the copper cells, and the row of points *z z'* will represent the extremities of the wires soldered to the zinc plates.

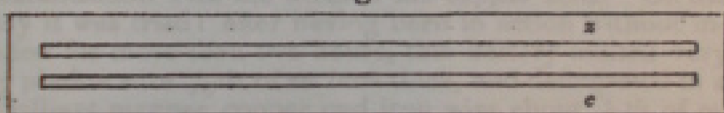
The acid solution is poured into the copper cells, which are water-tight, and is let out, without lifting the cells, by means of a cock at the bottom of each cell. The cells are barely wide enough to allow the free ascent and descent of the zinc plates. About 30 gallons of fluid are required to charge the whole battery. Both sides of each zinc plate are exposed to the action of the acid mixture, and are within about a quarter of an inch of an equal and parallel surface of copper. Hence the acting surface in each plate is 8 square feet, and the acting surface of zinc as well as of copper in the whole battery is 160 square feet.

By eight mercury troughs, metallic communications may be formed between the 20 zinc plates and the copper cells, so as to make the whole act as a single pair of plates, each containing 160 square feet of surface; or as 2 voltaic circles, in which

the zinc of each circle would contain 80 square feet; or as 3 circles, two of which would contain 56 square feet of zinc, and the third of which would contain 48 square feet; or as 4 circles, in each of which there would be 40 square feet of zinc; or as 5, in each of which there would be 32 square feet of zinc; or as 6 circles, four of which would each contain 24 square feet, and two of which would each contain 32 square feet of zinc; or as 10 circles, in each of which there would be 16 square feet of zinc; or as 20 circles, each of which would contain 8 square feet of zinc.

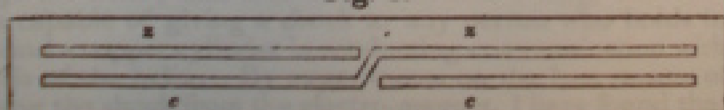
The mercury troughs are made by cutting holes for containing mercury in a piece of wood $3\frac{1}{2}$ feet long, $3\frac{1}{2}$ inches broad, and 2 inches thick. The mercury trough by which all the zinc and copper plates are made to act as a single pair, contains two parallel grooves, each nearly $3\frac{1}{2}$ feet long, $\frac{3}{4}$ of an inch wide, and an inch deep. One of the grooves receives all the wires of the zinc plates, and the other receives all the wires of the copper cells. Hence when mercury is poured into the two grooves, all the zinc plates are in metallic communication with each other, and act as one plate; and all the coppers likewise act as one copper plate. This trough is represented in fig. 4.; the letter *z* shows the groove for the wires of

Fig. 4.



the zinc plates, and *c* the groove for the wires of the copper cells. In the second mercury trough there are four grooves, each of which receives 10 wires. There is a communication between one of the grooves containing the wires of ten copper cells, and that which receives the wires of the zinc plates immersed in the remaining 10 cells. Fig. 5. represents this

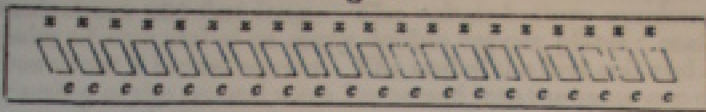
Fig. 5.



trough. The third trough contains 6 grooves; the fourth, 8; the fifth, 10; the sixth, 12; and the seventh and eighth each contain 20. Except the trough by which the battery is made to act as 20 voltaic circles, the rest are made like the trough represented in fig. 5. When the battery acts as 20 circles, the wire of each zinc plate, and the wire of the next

copper cell, are in the same mercury hole. Fig. 6. represents

Fig. 6.



the upper surface of the trough by which all the zinc and copper plates are made to act as 20 circles.

From the preceding description of our battery, it is evident that the whole 20 zinc plates and copper cells may, by substituting one mercury trough for another, be made to act as a single pair, or as 2, 3, 4, 5, 6, 10, or 20 voltaic circles, and thus be made to supply the place of the calorimotor and of the battery hitherto used for electro-magnetic experiments.

So enormous is the quantity of electricity circulated by this battery when all the zinc and copper plates act as a single circle, that, on one occasion, after having acted without interruption for more than an hour, it rendered powerfully magnetic an electro-magnet on which were coiled 39 thick copper wires, each about 35 feet long, while the mercury in which the wires of the zinc plates were immersed, was connected by 6 copper wires, each $\frac{1}{5}$ of an inch thick and about 6 inches long, with the mercury in communication with the wires of the copper cells. On the fifth day it was tried: after having been in action without interruption for more than two hours, this battery melted very rapidly platina wire $\frac{1}{30}$th of an inch thick, and deflagrated in a most brilliant manner copper and iron wire about $\frac{1}{12}$th of an inch thick.

By this battery, with the aid of an electro-magnet, a current of electricity may be produced which will equal in intensity that of a battery containing 1000 voltaic circles. It is well known that when the connexion between the helix of an electro-magnet and the voltaic battery is broken, a current of electricity is, at the moment of breaking the connexion, made to flow through the helix; and that when the helix is long, that current is capable of giving a shock to any person who holds in each hand a copper cylinder in conducting communication with the ends of the helix. By experiments on the best means of obtaining the shock from the electro-magnet, I have found that the shock increases, within certain limits, with the length and thinness of the bar of soft iron, and with the length of the heliacal coil, as far perhaps as 200 feet, and in proportion, or nearly in proportion, to the number of plates in the voltaic battery from which the current of electricity is passed through the helix. The shock does *not* increase in proportion to the number

of plates unless they are large. The electro-magnet which I first used was a straight bar of soft iron, about 2 feet long, and an inch thick. On this bar were coiled two copper wires, each about 200 feet long. The voltaic battery consisted of 14 pairs of zinc and of as many double copper plates: each plate was about 7 inches square. The end of the first coil and the beginning of the second were immersed into the same cup of mercury, the voltaic current was passed through the first coil only, and the shock was taken by making a communication with the beginning of the first coil and with the end of the second. When the current of electricity was passed through the helix from one pair of plates, the shock received on breaking contact with the battery was equal to that of a battery containing 20 pairs of plates. When two pairs of plates were used, the shock appeared to be doubled; with three voltaic circles, it appeared to be trebled; and with every increase in the number of voltaic circles, there appeared to be a proportional increase of the shock. With the 14 pairs of plates the shock was so strong that a person who took it, from an electro-magnet on which there were four coils of wire, felt the effects of it for several days. With a battery of 4-inch plates the shock increased with the number of plates, but not so rapidly as when large plates were used. I am inclined to think that with a battery of 4-inch plates, the shock increases but little when the number of plates exceeds a hundred. I could not induce any one to take the shock from the electro-magnet when a greater number than 16 of our large plates were used. With 16 of them the shock was exceedingly strong, although the acid mixture employed in charging the battery was very weak; and, from experience, I know that the electro-magnetic effects of a battery depend very much on the strength of the charge.

From all the experiments which I have made on the magneto-electric shock, I think I may fairly conclude, that, if 2000 feet of wire were coiled on a bar of soft iron 6 feet long and an inch thick, a shock might be obtained with the aid of a single pair of plates, which would equal that of a battery of 100 voltaic circles. Hence, since the shock increases in proportion to, or, at least, very rapidly with the number of plates, when they are large, the shock given by such an electro-magnet magnetized by our battery of 20 pairs of plates, should nearly equal, or perhaps exceed that of a battery of 1000 voltaic circles. Hence, by our battery of 20 pairs of plates, an electric current of the highest intensity may be produced. This battery then supplies the place of all the various kinds of galvanic batteries.

The shock given by the electro-magnet may be obtained

as often as the connexion of the helix with the battery is broken. Now I have devised a small instrument by which communication with the battery may be broken and renewed 3000 or 4000 times in a minute. Thus 3000 or 4000 shocks may be received, and 3000 or 4000 electric currents of the highest intensity may, in the space of one minute, be passed through water, charcoal, metallic wires, or any other body. It should be remembered that the voltaic current from the battery should not be passed through more than 200 feet of the helical coil, and that the shock should be taken from the whole length of the helix.

When a voltaic current passes through a very long wire from a single pair of plates, the wire will give a shock at the moment of breaking contact with the battery. I have found that this as well as the shock from the electro-magnet increases with the number of plates.

I have made a great variety of experiments on electro-magnets. My object in these experiments was to ascertain four things: first, on what the quantity of attraction depends; secondly, on what the distance at which that attraction is exerted depends; thirdly, on what the shock depends; and fourthly, whether by a voltaic current from a large battery, a permanent magnet could be made, which would induce on soft iron magnetism equal to that which is given to an electro-magnet by a battery containing 20 large plates, or 300 four-inch plates. In these experiments I employed three different voltaic batteries, and electro-magnets of various forms. I used the large battery already described; a small battery of 14 pairs of plates, in which each zinc plate was seven inches square; and a Wollaston battery, containing 280 pairs of four-inch plates. Some of my electro-magnets were straight, and others of the horse-shoe form, and one was a square: the iron bars varied in length from 20 inches to six feet, and in thickness from two inches to half an inch. On one of these were coiled 39 copper wires, on another four, on a third three, and on others there was only one wire.

From the results of these experiments, I have deduced the following conclusions: First, that the quantity of attraction increases with the length of the bar of soft iron, at least as far as six feet, and with the thinness till it becomes about an inch; and that it increases nearly in proportion to the number of plates (when they are large) in the battery by which the electro-magnet is magnetized. When the plates are only four inches square the attraction increases, but slowly when the number exceeds 100. Secondly, that the distance at which attraction is exerted, increases also with the length and thickness of the

iron bar, and with the number of plates when they are large; but with small plates the increase is very gradual when their number exceeds a hundred. With twenty of our large plates, an iron bar, nearly $3\frac{1}{2}$ lbs. weight, was attracted to a horse-shoe electro-magnet through the distance of an inch, and with ten plates the same bar was attracted to the same magnet, only through the distance of about half an inch. Again, with the twenty plates, the attraction of the same magnet for a sewing-needle was sensible at the distance of 15 inches, and with ten plates the attraction was sensible at the distance of 10 inches. Thirdly, that the shock from the electro-magnet increases within certain limits with the length and thinness of the iron bar, and nearly in proportion to the number of plates when they are large.

When the voltaic current was sent from a battery of 280 four-inch plates, through the heliacal wire coiled round a steel bar about 20 inches long and an inch thick, the steel became almost as strongly magnetic as if it were iron; and when the connexion with the battery was broken, the steel did not retain more than about $\frac{1}{100}$ of its magnetism.

In a paper published in the last (August) number of the Philosophical Magazine, Dr. Ritchie says that the use of the electro-magnet in the apparatus for continued rotation was long since abandoned, because it was incapable of inducing magnetism in an iron bar at a distance. Now he will find that, if instead of a single copper and zinc plate, a battery of 20 pairs of large plates, or of 200 small ones be used, the electro-magnet will have a greater power of inducing magnetism at a distance than any permanent magnet.

The advantages of the battery I have described are, first, that it supplies the place of all the various kinds of voltaic batteries, of the battery for producing a large quantity of electricity of low intensity, of the battery for exciting a large quantity of electricity of the intensity necessary for the rapid fusion and deflagration of metallic wires, and of the battery for producing an electric current of high intensity; and secondly, that it enables a person to compare the power of the very same zinc and copper plates acting as a single pair, with their power when they act as 2, 3, 4, 5, 6, 10, or 20 voltaic circles.

Nicholas Callan.

Maynooth College, August 23, 1836.

XLII. *On the Stratification of Electric Light.* *By the* Rev. T. R. Robinson, *F.R.S. &c.**

N a communication on the Stratification of Electric Light in rarefied Media, which appeared in the Philosophical Magazine last July, Mr. Grove has described some facts which are in close tion to the cause of that phænomenon, of which the most ortant is this—If in the circuit of an induction-machine of ch an exhausted vessel forms a part, there be an interruption ch is gradually lessened till sparks just pass it occasionally, se sparks are blue, and have a single sharp sound; if the rval be still more diminished, they become yellow, burred, their sound is not so clear, but is attended with a slight z. Now he finds that the blue sparks do not form strata he vacuum, but that the yellow do, so that by regulating distance he can produce them or not at pleasure. He *thinks* blue are single, and the yellow double or multiple; and finds his a proof of his former opinion, that these strata are caused some peculiar action of compound discharges. Within the few weeks he has developed these views more fully in a lee- e at the Royal Institution.

Everything which comes from Mr. Grove bears the stamp of acity and power; and I read this paper with great interest; circumstances prevented me till recently from repeating its eriments. The results which I have obtained, show that its ding inference cannot be received as universal; for, *in the cir- stances of my experiments,* I always obtained strata when a spark sed, whether long or short, blue or yellow. Any one versed these inquiries knows how much the strata are modified by ht variations of apparatus, &c.; and some such have probably sed this discrepancy; I will therefore describe mine in some ail.

The induction-machine which was mostly employed, consists six sectional coils (the gift of my friend Dr. Callan), each con- ning 8000 feet of fine iron wire, not lapped, but insulated by elastic varnish. They are arranged, three on each of two tical primaries, having each 350 spires of No. 12 copper, and es of iron No. 17. Their internal terminals are below, con- ted in the centre; and the current is passed collaterally ough the primaries, so that the external terminals of the ex- me coils have equal and opposite tensions. The condenser 100 square feet of charged surface, which can be used in tions of 20 according to the battery power. The rheotome is reurial†; and the machine gives sparks of about one inch every Grove's cell used to excite it. A few words respecting

* Communicated by the Author.

† This kind of rheotome is the best which I have tried, giving sparks

these sparks may be found relevant to the present question. If the terminals be connected with a spark-micrometer opened to about twice the striking distance, when the machine acts, a lucid star will appear on one or both points. Bringing them gradually closer, a small brush, exactly like that produced by a point on a prime conductor, is seen at the positive point: as the distance is lessened, the filaments of this brush extend, and at last curve towards the negative with a sputtering sound. Still nearer, and sparks strike across with an intense light and sharp snap which cannot possibly be mistaken for the preceding form of discharge: they are zigzag; and, when the excitation is powerful, two-thirds of their length at the positive end is often red, the rest bluish white. If the distance be less, the spark has that strange yellow envelope which, as Du Moncel has shown, can be blown aside like a flame, but which is certainly not a second discharge*. And at very short distances there is sometimes a sheaf of curved sparks between the points. If one terminal be connected with the gas-pipes of the house, and the arm of the micrometer which had been joined to it be connected with the floor (so that the circuit includes a very great resistance), we obtain what is called the static discharge, which is of the same character as the inductive one discovered by Mr. Gassiot, and, like it, can be distinguished from the dynamic one by the magnet when passing through a vacuum and the revolving mirror in air: it is about half the length of the other. The vacuum which I included in the circuit was an "electric egg," 9′ high and 6′ diameter; on its wires were cemented glass tubes with Wollaston's points of platinum, $\frac{1}{50}$ diameter, 6′ apart. This form of electrodes reduces the conditions of discharge to a more definite state than when they are balls or naked wires; and the following may be considered its normal character when the egg has been filled with dry hydrogen and exhausted to 0′·08. Supposing the upper electrode positive, there is at it a brilliant

whose length is 1·3 times that of those obtained by the spring rheotomes of Hearder or Ladd: Ruhmkorff's vibrating hammer is much feebler. This very energy, however, tests the insulation of the coils severely. I find two precautions necessary in using it:—(1) the mercury must be negative, otherwise the action is almost explosive, and the effect only $\frac{1}{2}$; (2) the platinum points should work through a diaphragm of thin vulcanized rubber, to prevent the blackened alcohol from being splashed about.

* When such a spark is viewed in a revolving mirror, its thickness is slightly increased, but the envelope is drawn out into a sheet extending many degrees, even when the rotation is comparatively slow, which shows that it lasts much longer than the spark itself. This explains a singular fact which has occurred to me occasionally. In a hydrogen vacuum $=2''\cdot50$, if a small Leyden jar be connected with the machine, according to Mr. Grove's plan, the discharge passes as a splendid scarlet spark; this is sometimes surrounded by a faint elliptic envelope, which continues visible for 0″·1 after the other has disappeared.

oint, from which streams an elliptic spindle of greenish light r about two-thirds of the distance, brightest in the axis: is is full of strata, thick near the point and curved round it ce spheric shells, thinner below and less curved, till at the lower rmination of the positive light they are nearly plane and only ·05 or 0′·06 thick. In the bright central portion they seem icker than their continuations into the surrounding part, hich are also bent back abruptly. If the excitation be very owerful, the curvature of the lower strata is reversed, these eing in that case formed, as Mr. Gassiot has shown, by that urrent which passes on closing the primary circuit. Below the ositive light is a dark space from 0′·5 to 2′ wide; and lower till is an atmosphere of bright blue light (which I call the igrette). It is generally conical with a convex base, *never hows strata*, but seems to be composed of rays diverging from he negative point. From this, however, it is separated by thin dark space surrounding it like a wrapper, and within hat by a reddish-violet one. Along the glass tube, below this, ositive light with its strata reappears; due probably to the difiiculty of insulating the wire where the tube ends. If static ischarges be passed, the appearances *at each point* are similar— negative aigrette, a dark space, and a few thick spherical strata t each end of the faint spindle of light concave towards the earest point. This is explained by the double nature of this lischarge. If a static spark be viewed in the mirror revolving ighty times in the second, it is seen to consist of two, the econd narrower than the first and less luminous, about 5° ehind it, that is, nearly $\frac{1}{5000}$th of a second later: the two being pposite in direction, produce two reverse systems, which are nerely superposed.

Having premised so much, my trial of Mr. Grove's experiment can be easily described. Exciting the induction-machine by two Grove's, it gave static sparks = 0′·90, and dynamic = 2′·227 at the rate of 7 in 2ˢ. With the egg in circuit, no sparks passed till the micrometer was at 1′·038. During the whole of the previous star- and brush-discharges, the appearances in the egg were those which I have described as static, strata and aigrettes *at each* end, even when the micrometer was at 4′. The moment a spark passed (and, as I have already said, these cannot be mistaken), the strata appeared in their normal condition, merely increasing in brightness and magnitude till the micrometer was in contact. By no manipulation of it or the rheotome could I get a spark without producing them; nor, indeed, could I get any discharge through the vacuum without getting at least the static set.

On another occasion with three Grove's, the static spark was

02 and the other 2′·925; but, as before, I could get no *dis-ge without strata.* Then I examined the sparks, which were ially showing them splendidly, in the revolving mirror at the uest speed which I could manage, 120 in a second. There have been a few multiple, but only as exceptional; for in ost every instance they were certainly single with that speed, ch would easily show $\frac{1}{10000}$ of the second. I substituted the egg one of Mr. Gassiot's magnificent Torricellian tubes which, as well as much precious information and personal lness, I have to thank that gentleman). It is 1′ diameter, 31′·8 between the platinum points: whenever a spark passed micrometer, its peculiar strata appeared in their normal aty; but with the brush, they had the peculiar character ch Mr. Gassiot has shown to belong to discharges made by action through the glass; and placing the tube axial on a erful electro-magnet, it showed, as in his trials, the brush harges to be double in opposite directions, or, as he calls n, "reciprocating."

hese are not the only trials which I have made; but I inva-ly found that no length of spark prevents the formation of ta, and I am obliged to conclude that Mr. Grove's rule is absolute. The difference between our results depends btless on some unnoticed difference in the conditions under ch we operated. Among possible causes may be named the nature of the vacuum. He used air with phosphorus our diffused in it; I hydrogen: I prefer that, as definite in ire, as with equal air-pumps giving a rarefaction fourteen s greater, and as exhibiting these strata better than any ium with which I am acquainted, except mercurial vapour. The sort of electrodes. Believing the strata to depend on a liar mode of disruptive discharge, I think they will be ed most certainly when the electric power is concentrated a narrow area, as in the guarded points which I used. The direction of the current. When the upper electrode is tive, they are better developed than when it is negative; in latter case there are often only a few large ones near the r point, and the rest are lost in luminous haze, the ascend-currents of the heated medium probably confusing them. Still more important is the intensity of the electricity: with weak power (which would give an air-spark of 0′·1 or 0′·2) ve failed in obtaining them, even in the Gassiot tube. On other hand, excessive power fails also, but in a different way, lucing but concealing them. If, when my six coils are ly charged, the discharge of one, two, &c. be passed in suc-on, it is seen that the bright strata throw out cloudy ap-lages into the dark intervals as the intensity increases, so

at with one giving 5′ sparks, the latter are filled with light. Mr. Gassiot found the same effect from increasing the number of battery cells; and I believe that his gigantic American machine scarcely shows any stratification.

But even were it universally true that a spark of sufficient length interposed in the circuit prevents the appearance of strata, still Mr. Grove's theory of their origin would remain subject to weighty objections. We have no experimental evidence that the current which he supposes to succeed the extra current in the primary coil, exists with any sensible energy; and, granting its existence, it is not easy to see how it can produce the effects assigned to it; for, apparently, it must be *subsequent* to the discharge of the secondary coil, and therefore cannot modify that in any way. A synchronous one, we know from experiment, only weakens the force of another that is opposite; and in the static discharge, where there is the very system which he requires, a discharge followed at a very small interval by a weaker opposite one, there is certainly no special power of developing strata.

A different view of their origin, and one which seems nearer the truth, is given in the Number of 'Cosmos' for the 4th of last month, by M. Morren of Marseilles. He thinks they are caused by periodical variations of intensity in the current, due to the resistance which it meets in traversing an imperfect conductor, and that these cause lateral discharges of the conducting material; he therefore compares them with the wings that project from the stains made by exploding fine wires over paper by an electric battery. The notice is so brief, that I supposed he meant to represent these explosion-pictures as "autographies des stratifications de la lumière électrique;" but the meaning of this phrase is made clear by another notice in the same journal (Feb. 18) from M. Seguin, who also seems to have obtained the same result. An induction spark sent along glass dusted with fine charcoal, leaves a track whose markings he considers identical with the strata. Undoubtedly these variations of intensity do exist: they are shown by the fracture of a wire into minute pieces when the discharge is not quite sufficient to fuse it, and still more plainly by sending the static discharge of a powerful induction machine through a fine steel wire some feet long. In air of ordinary density, and still more in rarefied air, the wire is luminous; but at every inch or two it throws out a circle of brushes. In the exploded wire, or the air over the glass, the same thing happens; but the brushes carry with them most of the metallic vapour or the charcoal dust, leaving a deficiency of them at the intermediate points. On repeating M. Seguin's experiment, I obtained the appearances which he describes:

they have a strong resemblance to the explosion-pictures, and also to the yellow envelope already referred to as surrounding short sparks; but, as it seems to me, their analogy to the strata is far from complete. The transverse divisions scarcely ever go entirely across, and have no regularity; the jagged fringes and serrated points which form the outline, are in strong contrast with the smooth and comparatively definite boundary which the light often shows; but, above all, the markings extend through *the whole* track of the discharge, and there is nothing analogous to the dark space or the blue negative light. In fact the two sets of phænomena seem to belong to different categories: one is the transfer of matter laterally from the axis of discharge by a vehement repulsion; the other is a succession, along a certain portion of that axis, of fits of discontinuity in the light-producing power of the current. That power, for a certain further distance, totally ceases, to reappear without any intermission, and with the development of rays of higher refrangibility. It is certainly possible that, in rarefied air, these so-called autographs might assume a similar character; but unless this prove to be the case, I think it will be felt that some further step is necessary to complete the explanation. As it now stands, any one who compares a fine set of strata with (for example) the superb drawings of exploded wire in Van Marum's *Description d'une très-grande machine Electrique*, will scarcely admit them to be results of the same action, that of mere repulsive force.

It has been for some time my own opinion that the strata are caused by these periods of intensity, but in a different way from that just mentioned,—by the successive zones along the axis becoming charged up to the point of disruption. I feel, however, that any exposition of it must be premature till more facts are collected, and still more till we have a mathematical investigation of a current's motion in an imperfect conductor. While such labourers as Faraday, Gassiot, and Grove himself are in the field, we can have little doubt that the harvest will not be long unreaped; and we may surely expect that some powerful mind will ere long bring within the domain of analysis the hypothesis (which every day confirms) that electricity is, as Grove expresses it, "a mode of motion." Such an investigation is, from its correlation to other molecular forces, of the highest importance, and will certainly reward most amply its author.

Armagh Observatory, March 7.

ness were less than this, the resultant of the cohesive force would be less, and the crust would crack at some intermediate point.

Every physical consideration seems to indicate that the crust must be very thick; and the only real calculation of its limiting thickness on physical principles, viz. that of Mr. Hopkins, should be received.

The form the surface at present exhibits may be supposed to have arisen from the contraction and expansion of the parts of this thick crust since it first began to form, producing hollows in which seas and oceans have gathered together their waters, and elevations in continents, table-lands, and mountains; and therefore the variations of the surface, under its present aspect, are not at all regulated or produced by hydrostatical principles.

J. H. Pratt.

Calcutta, Feb. 22, 1859.

LII. *A brief Account of an Induction Coil of great power in proportion to its length. By the* Rev. N. J. Callan, *D.D., Professor of Natural Philosophy in Maynooth College**.

In the construction of induction coils, the principal object of some seems to have been to make the coil in such a way, that with a given length of secondary wire the longest sparks may be obtained. It appears to me that it would be better to make induction coils so that, with a given battery, sparks of the greatest length may be produced. The longer the coil is, the greater will be the resistance of the primary wire to the current of the battery, and the greater the number of cells which will be required to overcome that resistance and saturate the core with magnetism. Hence it is a matter of great importance to make coils in such a way that, whilst they are short, they may produce very long sparks. I have endeavoured to do this; and though the primary and secondary coils of the induction coil I have made are very imperfect, I have succeeded tolerably well.

The primary coil is made of thick copper wire about 140 feet long: it is 10 inches in length. The conducting power of the copper wire was injured by being frequently coiled on electro-magnets, or on cores of induction coils.

The secondary coil consists of three small coils: two of them are $1\frac{3}{4}$ inch long, the third is only $1\frac{1}{2}$ inch. Hence the entire length of the secondary coil is 5 inches. It is only half the length of the primary coil, and is therefore not finished. The secondary coil is made of iron wire, No. 34 gauge; the thickness of the wire is about the $\frac{1}{100}$th of an inch. The wire is covered only partially with cotton thread. Between each two ad-

* Communicated by the Author.

joining spirals of the thread wound on the wire, there is sufficient room for another spiral of thread, and on a great part of the wire there is space enough to admit three or four threads. I adopted this mode of covering the wire in order to save time. With the same view, I arranged our machine for winding thread on wire so that by one and the same operation I covered the wire with thread and wound the wire on the coil. I fear that in many parts of the coil the bare or uncovered part of one wire is in contact with some parts of the adjoining wires. Each layer of spirals is brushed over with a hot solution of gutta percha dissolved in rosin oil. The solution is so thick, that when cool it takes the form of a paste. Each layer of spirals is insulated from those of the layer above and below it by paper saturated with the solution of gutta percha, in the manner described in the paper which I read at the Dublin Meeting of the British Association in 1857, and which was published in the Philosophical Magazine for the following November. I have in one instance seen sparks passing through the three thicknesses of paper, by which the spirals in one layer are insulated from those of the one above it. Hence the insulation of each layer of spirals from those above and below it is defective.

In trying the two parts of the coil which were first made, I observed, as often as sparks passed between the terminals of the coil, a great number of very minute sparks on the outside of one of the two parts. This made me suspect that these sparks were passing from some spirals to the adjoining ones. When I had finished the third part of the coil, I abstained from brushing over the outside spirals with the solution of gutta percha, in order to see whether sparks would pass from one spiral to another. As soon as the battery was connected with the primary coil by means of our mercurial contact-breaker, sparks passed from the bare parts of several wires to the contiguous ones. When any part was brushed over with the gutta-percha solution, the sparks ceased there, but became more numerous in some other part.

This coil, though only 5 inches long, has, notwithstanding all its defects, given sparks $4\frac{1}{8}$ inches in length with three cells of the Maynooth battery, each 4 inches square. I have not seen an account of any coil which with so small a battery has given sparks so long in proportion to the length of the coil. On account of the imperfect insulation of the secondary coil, I am afraid to use a more powerful battery.

I intend to make a new primary coil about 36 inches long, and twelve small secondary coils, each about 2 inches in length. From this coil I expect to get, with a small battery, sparks 20 or 24 inches long.

I have made several interesting experiments on the various

parts of the coil, which I have not time at present to describe. Many more remain yet to be made. When they are finished, I shall prepare an account of them for publication in the Philosophical Magazine.

My object at present is, first, to show that iron wire, though far inferior to copper in conducting power, is not unfit for secondary coils; secondly, to direct attention to the importance of making induction coils so that with a given length, not of the secondary wire, but of the coil, the longest sparks may be produced; and thirdly, to show that a mere covering of the secondary wire with thread of any kind is not sufficient to insulate the spirals of any layer from the adjoining ones of the same layer.

Maynooth College, April 4, 1859.

LIII. *On a New Form of Telegraph Cable intended to reduce the effects of Inductive Action.* By J. N. Hearder, *Electrician, Plymouth**.

In my last paper I described the nature of the inductive action which takes place during the transmission of electrical currents through insulated submarine conductors, and pointed out the various disturbing influences which it occasions. It is now pretty well admitted by telegraph engineers, that, unless these impediments to the free and rapid transmission of signals can be either entirely removed or considerably lessened, the commercial value of very long lines will be somewhat in the inverse ratio of their lengths. As, however, the mechanical engineer has overcome the difficulty of laying telegraph cables, it now remains for the electrician to overcome the scientific difficulties which beset his path, and to render his line of communication thoroughly efficient after it is laid.

Of late much attention has been directed to the subject, and some very able communications from practical electricians have contributed to throw much light upon it. From the very first moment when the static charge of the gutta-percha coating was brought under my notice, I felt that it would one day act as a formidable barrier to the extension of submarine lines; and I saw at that time no chance of remedy, except in the employment of larger conductors and thicker insulating coatings. Within the last year or two, plans have been proposed to reduce the amount of induction, some of which appear to be founded upon an incorrect apprehension of the electrical phænomena to which such arrangements would give rise. For instance, it has been

* Read at the Plymouth Institution, March 3, 1859. Communicated by the Author.

THE
LONDON, EDINBURGH, AND DUBLIN
PHILOSOPHICAL MAGAZINE
AND
JOURNAL OF SCIENCE.

[FOURTH SERIES.]

JUNE 1863.

LVI. *On an Induction Coil of great power, and on the effects of connecting Plates with the ends of the Secondary Coil.* By the Rev. N. J. Callan, *D.D., Professor of Natural Philosophy in St. Patrick's College, Maynooth*.*

ABOUT three years and a half ago I made an induction coil of considerable power. The secondary coil, which was made of No. 34 iron wire, consisted of three parts, two of which were each about 2½ inches, and the third 3 inches long. The entire length of the secondary coil was about 8 inches, and the length of the secondary wire about 150,000 feet. The mode of insulation is nearly the same as that of the coil described in the Philosophical Magazine for May 1859, except that thin sheet gutta percha is used for insulating the spirals of one layer from those of the adjoining layers. With three cells of the Maynooth battery, in each of which the zinc plate was 4 inches square, the coil gave sparks about 10 inches long between two pointed wires, one connected with each end of the coil. With five cells of the same size, the sparks were only 10½ inches, but were much louder than the sparks produced by three cells. Within the last four months I made a new primary coil nearly 3 feet long with a core about 3 feet 6 inches in length, and improved the insulation between the secondary coil and the primary, and also the insulation of the three parts of the secondary from each other.

Since these changes were made, this coil (the negative end being connected with a plate containing a square foot of surface, and the positive end with a pointed wire) gave sparks 7½ inches long with a single 4-inch cell of the Maynooth battery. With two 4-inch cells the sparks were 12½ inches, and with three cells of the same size they were 15 inches in length.

* Communicated by the Author.

When the sparks were taken between two pointed wires, they were only 6 inches with one, and a little more than 13¼ inches with three 4-inch cells. Hence, when the negative end is connected with a plate a foot square, the sparks are 1½ inch longer with one cell and 1¾ inch longer with three cells than when each end of the coil is connected with a pointed wire.

When the negative end was connected with a circular brass plate 4 inches in diameter, and the positive with a pointed wire, the sparks with one cell were 6¼ inches, and with three cells they were 13½ inches. Therefore when the negative end is connected with a plate a foot square, the sparks are 1¼ inch longer than when it is connected with a 4-inch circular plate.

Since I discovered the great increase produced in the length of the spark by connecting a large plate of any metal with the negative end of the coil, I made a series of experiments in order to ascertain the best size of the plate, and the effects of connecting plates in various ways with the ends of the coil. Some of the results of these experiments appear to be anomalous, and not in accordance with the commonly received theory regarding the distribution of electricity over the surface of bodies, nor with the rule for determining the height to which a lightning conductor should project above the roof of a building to which it is attached.

First, with regard to the size of the plate necessary to produce the longest spark, I have found that a circular metallic plate 7 inches in diameter is sufficiently large when the spark does not exceed 10 inches, and that a piece of wood 9 inches square produces the same effect as the 7-inch plate. I commonly use a circular plate of tin about 12½ inches in diameter. With this plate the coil gives a spark an eighth of an inch longer than with a plate containing four square feet of surface. In order to get the longest spark from a coil, the outer end of the secondary coil should be positive, and the inner end negative; the plate should be connected with the negative end, and the pointed wire with the positive end, and the central part of the plate should face the point of the wire. When the plate faces the point, and its circumference is opposite the point, the sparks are a little shorter than when the point is opposite the middle of the plate.

Secondly, with regard to the effects of plates connected with the ends of the coil, I have found that the effects of a plate in connexion with the negative end differ very much and in various ways from those that are produced by a plate connected with the positive end.

In most of my experiments on this subject the greatest length of spark the coil was capable of giving with the three cells em-

ployed varied from 13½ to 15 inches. When I used a weaker battery I mention the length of the spark. The plate was about 12½ inches, and the point was opposite to the middle of the plate, except when the contrary is expressed.

First, when a pointed wire is connected with the positive end of the coil, a plate connected with the negative end lengthens the spark considerably; but when the pointed wire is connected with the negative end, a plate connected with the positive one shortens the spark in a greater proportion. Sparks which were 15 inches long in the first arrangement were reduced to less than 11 inches by the second; they did not pass at all between the positive plate and negative point until the plate was brought within 8½ inches from the point.

Secondly, sparks from a positive point to a negative plate never went to the circumference of the plate, and scarcely ever struck the plate at a greater distance from the centre than 3 inches. But sparks between a negative point and positive plate always went to the circumference until the plate was brought within 2½ or 3 inches from the point: even when I used a rectangular plate 20 inches broad and 28 inches long, the sparks went to the edge of the plate.

Thirdly, the sparks from a positive point to a negative plate never moved in a straight line, even when the point was less than an inch from the plate. But when a negative point is brought within 2½ or 3 inches, or even less than an inch from a positive plate, the sparks pass in a straight line between the point and the nearest part of the plate.

Fourthly, the sparks from a positive point to a negative plate grow weaker and less loud as the point is made to approach the plate. But when a negative point is brought within two or three inches from a positive plate, the sparks become as loud as if the plate were charged, or as if they were produced by a small Leyden jar whose opposite coatings were connected with the ends of the coil. With a plate containing four square feet of surface, the sparks were louder than with the 12-inch plate. A hollow ball connected with the positive end of the coil also gives very loud sparks. Hence a plate or ball connected with the positive end becomes charged, but a plate connected with the negative end does not.

Fifthly, when a pointed wire nearly ¼ of an inch thick projected 6½ inches from the middle of the 12½-inch circular plate connected with the negative end of the coil, and nearly at right angles to the plate, and another plate of the same size was connected with the positive end, the sparks passed not between the point and positive plate, but from the circumference of one to the circumference of the other, although the distance of the point

from the plate was less than 4 inches, and the distance between the circumference of one plate and that of the other was 10 inches. But when a pointed wire projected more than three-fourths of an inch from the middle of a plate connected with the positive end of the coil, and the other plate was connected with the negative end, the sparks passed from the point to the negative plate, and never from the circumference of one to that of the other.

Sixthly, when a pointed wire projected from the negative plate at about half an inch from its circumference, and 3½ inches from the plate, the sparks passed even then far less frequently between the point and the opposite circumference of the positive plate than between the circumference of one and that of the other plate. But no such effect will take place when the pointed wire projects from the positive plate.

When a pointed wire projected 3½ inches from the middle of a wet slate about 9 inches square, or 2½ inches from the middle of a wet piece of wood of the same size, connected with the negative end of the coil, and the 12½-inch plate was connected with the positive end, the sparks passed between the circumference of the plate and the edges of the slate or wood, rather than between the point and plate. When the slate or wood is dry, the sparks passed from the pointed wire to the positive plate. When the wood or slate is merely damp but not very wet, the sparks from the wire frequently run to the edge of the slate or wood and then pass to the plate. If the wire project from the wood or slate near the edges, the sparks will pass between the point and positive plate, unless when the pointed wire projects to a small distance from the wood or slate.

A ball 3 inches in diameter connected with the positive end shortens the spark as much as a 12-inch plate.

When a pointed wire is opposite the edge of a plate connected with the negative end, the spark is longer than between two points, but shorter than between a positive point and the middle of a negative plate.

When two plates are connected with the ends of the coil and face each other, the spark is reduced from 15 inches to about 11 inches. When their edges are opposite to each other, the spark is also shortened.

I have repeated most of the above-mentioned experiments with a weak battery which gave sparks 7 or 8 inches long, and obtained the same results. When the sparks are about 8 inches, the plate connected with the end plate should not be more than 7 inches in diameter. When I connected the 12½-inch plate, or a 3-inch hollow ball, with the positive end (the longest spark being about 8 inches), no spark passed between the plate or ball and a negative point until the point was brought within about 2

inches from the plate, or until the sparks resembled the discharges of a small Leyden jar. The sparks never passed between the point and circumference of the plate. It was otherwise when I used a 7-inch plate. Hence the size of the plate connected with the positive end of the coil must depend on the power of the coil employed. The pointed wire used in all the experiments was nearly $\frac{1}{4}$ of an inch thick.

I have not as yet had time to give a fair trial to the coil with a battery of greater power than that of three 4-inch cells. With one cell in which the zinc plate was 4 inches by 8, I got sparks $8\frac{1}{4}$ inches long when the plate connected with the negative end was only 4 inches in diameter. Had I known at the time that with a 12-inch plate the spark is $1\frac{1}{4}$ inch longer than with a 4-inch one, the sparks with the single cell 4×8 would have been $9\frac{1}{2}$ inches long. I intend to try the coil as soon as convenient with a battery of twelve 6-inch cells, and six cells 4 inches by 8.

St. Patrick's College, Maynooth,
May 13, 1863.

LVII. *On Celestial Dynamics.* By Dr. J. R. Mayer.

[Concluded from p. 409.]

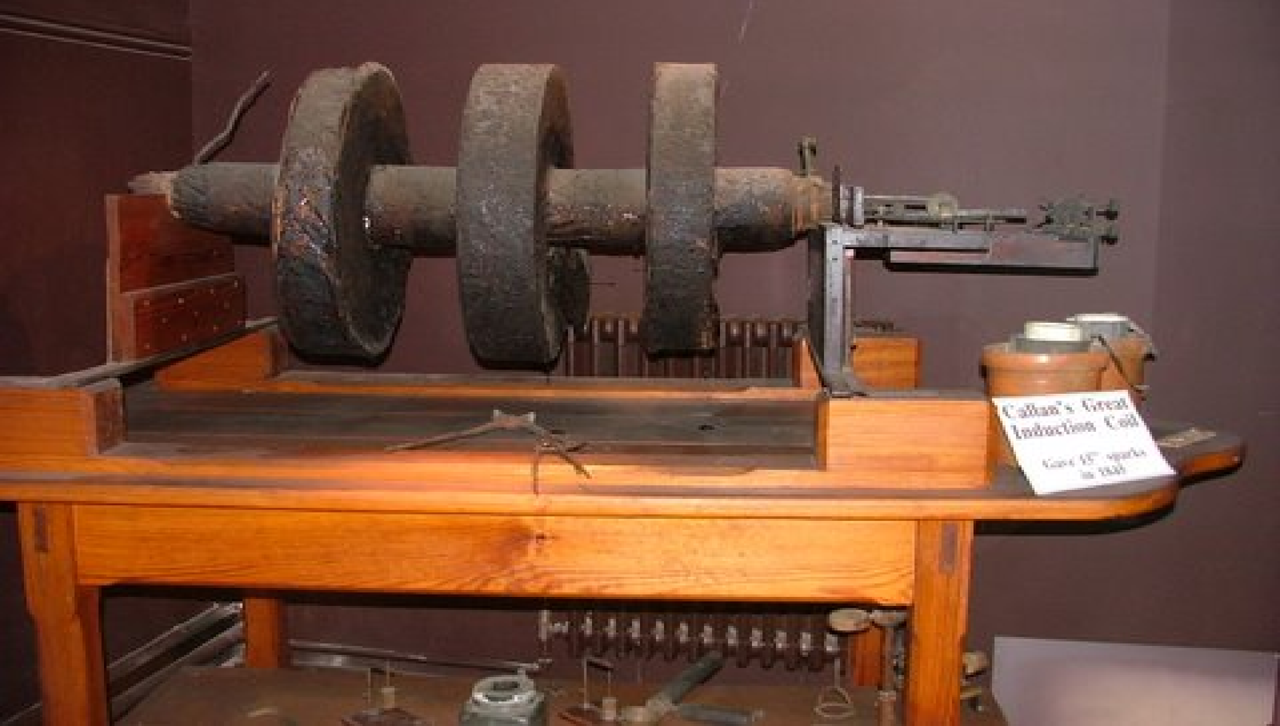
IX. *The Heat of the Interior of the Earth.*

WITHOUT doubt there was once a time when our globe had not assumed its present magnitude. According to this, by aid of this simple assumption, the origin of our planet may be reduced to the union of once separated masses.

To the mechanical combinations of masses of the second order, with masses of the second and third order, &c., the same laws as those enunciated for the sun apply. The collision of such masses must always generate an amount of heat proportional to the squares of their velocities, or to their mechanical effect.

Although we are not in a position to affirm anything certain respecting the primordial conditions under which the constituent parts of the earth existed, it is nevertheless of the greatest interest to estimate the quantities of heat generated by the collision and combination of these parts by a standard based on the simplest assumptions.

Accordingly we shall consider for the present the earth to have been formed by the union of two parts, which obtained their relative motions by their mutual attraction only. Let the whole mass of the present earth, expressed in kilogrammes, be T, and the masses of the two portions $T-x$ and x. The ratio of these two quantities may be imagined to assume various


Callan's Great
Induction Coil

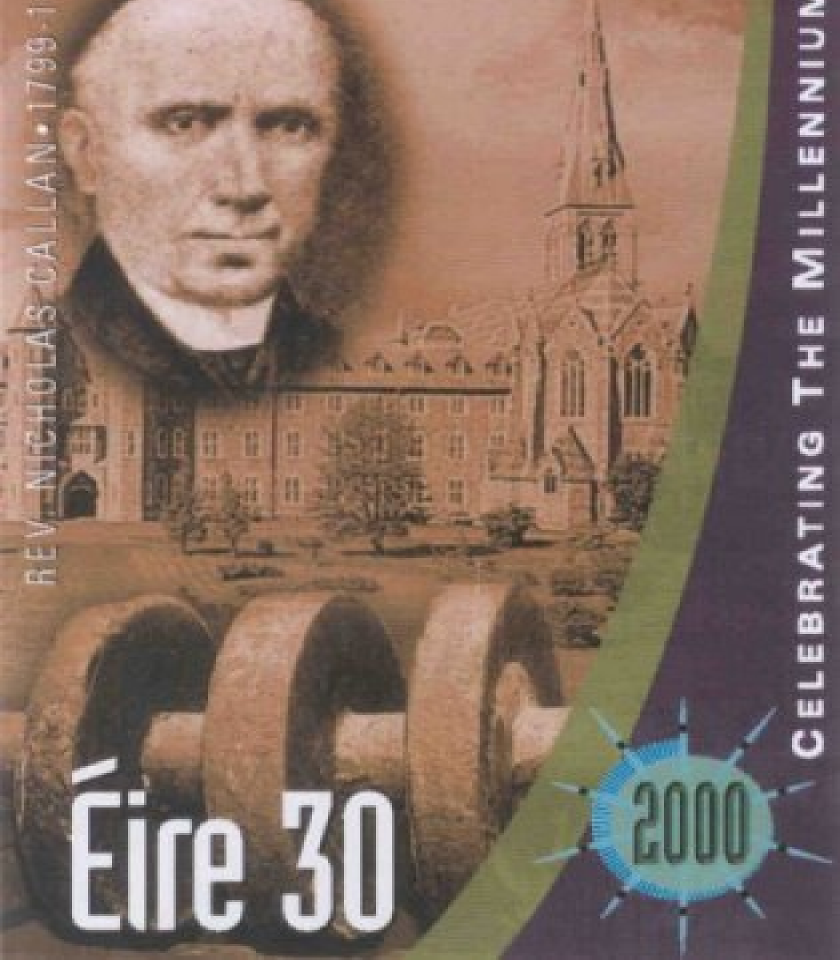
IEEE MILESTONE IN ELECTRICAL ENGINEERING AND COMPUTING

CALLAN'S PIONEERING CONTRIBUTIONS TO ELECTRICAL SCIENCE AND TECHNOLOGY
1836

Reverend Nicholas Callan (1799 - 1864), professor of Natural Philosophy at Saint Patrick's College, Maynooth, contributed significantly to the understanding of electrical induction and the development of the induction coil. He did this through a series of experiments that made the inductive transient phenomena visibly clear. The apparatus used in these experiments was replicated in other laboratories.

September 2006

INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS


REV. NICHOLAS CALLAN • 1799
CELEBRATING THE MILLENNIU
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MAYNOOTH
BATTERY
E.M.CLARKE
MAKER
428 STRAND
LONDON

071 CALLAN MEDIUM SIZED INDUCTION COIL - c1857

Unsigned - made by Nicholas Callan.

The primary coil of heavy copper wire, insulated with cotton thread, is wound on a bundle of annealed iron wires. The primary is insulated from the secondary by an ebonite cylinder. The secondary coil is of light iron wire insulated with melted rubber and bees-wax. The coil is fitted with a McGauley type interrupter: a vertical iron bar is secured at the bottom, and has a small iron cylinder attached to the upper end, which makes or breaks contact with the core of the electromagnet. A turned brass pillar holds a screw, which makes or breaks contact with the bar. The coil is also fitted with a Rühmkorff-type commutator ***(096)****, consisting of a mounted ebonite cylinder which can be turned by an ebonite handle: the cylinder is fitted with two brass plates, which make alternating contact with two brass springs. There are two pillars, which hold point electrodes with glass handles.*

Callan described his newly-made coil, with a secondary of iron wire of 21,000 feet (later increased to 50,000 feet), which he demonstrated to the Dublin Meeting of the British Association for the Advancement of Science in 1857.

James William McGauley (c1806-1867), who was Professor of Natural Philosophy to the Board of Education in Ireland from 1836-1856, was an "independent inventor" of the "automatic hammer contact breaker" which he described in 1837. He used a mercury contact-cup, but this was soon replaced and the interrupter became the

105 CALLAN CONDENSER - c1857 R.

Unsigned - made by Nicholas Callan

A condenser is an apparatus for condensing a large quantity of electricity on a comparatively small surface. They are now called capacitors, and the insulating materials are called dielectrics. The use of a condenser improved the operation of induction coils by reducing the spark between the "hammer and anvil" of the interrupter, thus prolonging their lives.


St Patrick's College

Callan Medium Sized Coil 1857

Callan's medium sized coil has a primary of heavy copper wire, insulated with cotton thread, and is wound on a bundle of annealed iron wires. The primary is insulated from the secondary by an ebonite cylinder. The secondary coil is of light iron wire insulated with melted rubber and bees-wax. Callan replaced his "repeater" with a McGauley type interruptor or trembler. The output of the secondary coil is connected to two point electrodes, with glass handles, mounted on two pillars.

Large sparks jumped between the two electrodes. Voltages generated by this medium sized coil were of the order of 200,000 Volts.

XLIV. *A description of an Electro-magnetic Repeater, or of a Machine by which the connexion between the Voltaic Battery and the helix of an Electro-magnet may be broken and renewed several thousand times in the space of one minute. By the* REV. N. J. CALLAN, *Professor of Natural Philosophy in R. C. College, Maynooth.**

Fig. 52, Plate VII, is a side view of the machine which I have devised for rapidly breaking and renewing communications with the voltaic battery. This machine consists of a mahogany base A B, of the swing wheel V N O (Fig 53), of the pallets R S, and of the five mercury cups, C, D, E, F, and G. The swing wheel is supported in a vertical position by its axis, which rests on the upright brass plates, *o*, *x*, and *r*, *s*, *t* (Fig. 52). The teeth of the wheel V N O appear at *n*, between the two brass plates. The wheel is turned by the handle H. The pallets are also supported in a vertical position by the axis M Y, which rests on the upright brass plates, *o*, *x*, and M L. To the axis M Y of the pallet is soldered, at K, a thick copper wire *a*, *b*, which is bent so as to form a right angle at each end. At K, under the axis M Y, is soldered a short wire (not shown

* Communicated by the Author.

in the figure) which is always immersed in the mercury of the cup D. The mercury in the cup C, is always connected with the mercury in the cup E, by the bent copper wire *e*, *e*. To each mercury cup is fitted a cover in which holes are made for admitting wires into the mercury. The beginning of the thick wire coiled round the electro-magnet is immersed in the cup E and the end of the same wire in the cup F. The end of the thin wire soldered to the thick one, and coiled on the electro-magnet, is immersed in the cup G. One end of the voltaic battery is always connected by a copper wire with the mercury in the cup D, and the opposite end with the mercury in F. When the extremity *b*, of the wire *a*, *b*, is immersed in the mercury in the cup E, the voltaic current from the battery passes through the thick wire coiled on the electro-magnet, and magnetizes the iron bar. When the same extremity *b* is raised out of the mercury, the communications between the battery and the helix of the magnet is broken, and an electric current capable of giving a shock is excited in the magnetic helix. When the extremity *b* is raised out of the mercury in the cup E, the opposite extremity *a*, of the same wire is depressed and immersed into the mercury in C, and the communication between the magnetic helix and the battery is renewed. Thus by every oscillation of the wire *a b*, the communication between the helix of the electro-magnet and the battery is broken and renewed. If there be thirty teeth in the swing wheel V N O, one revolution of that wheel will cause 60 oscillations of the pallets R and S, and consequently 60 oscillations of the wire *a b*. Hence by turning the handle H, once in a second 60 electric currents of high intensity will be produced in the magnetic helix in the space of a second; or 3600 electric currents in one minute. These currents will pass through any body interposed between the beginning of the thick wire and the end of the thin wire, that is between the mercury in the cup F or C, and the mercury in the cup G.

Maynooth College. N. J. CALLAN.

ELECTRO-MAGNET YET CONSTRUCTED. BY THE REV. N. J. CALLAN, PROFESSOR OF NATURAL PHILOSOPHY IN THE R. C. COLLEGE, MAYNOOTH.

(From Sturgeon's *Annals of Electricity* for July).

I have lately constructed for the College, an electro-magnet which far surpasses in electric and magnetic power, all the electro-magnets of which I have been able to find a description. The iron bar of our magnet weighs 15 stone; it is 2½ inches in diameter, and more than 13 feet in length. It is bent into the form of a horse-shoe: the distance between the poles is 7 inches. A copper wire, one-sixth of an inch diameter, is coiled once round the whole length of the iron bar. This wire is divided into seven parts, each about 70 feet long. A thin copper wire, about one-fortieth of an inch in diameter, is soldered to one of the thick wires at about a foot from one of its extremities. The thin wire is about 10,000 feet long; it is wound round the magnet in the same direction as the thick wire, and in one continuous coil. By connecting the opposite ends of the seven thick wires with the opposite poles of a powerful galvanic battery, an extraordinary magnetic power is communicated to the iron bar; and, by breaking battery communication, an electric current of enormous intensity is excited in the long coil of thin wire. I have tried the magnetic and electric powers of this magnet only once. In consequence of making the trial, in presence of about 300 of the students, I was compelled to omit many of the experiments which I intended to make, and which I expect to make before the end of this month.

In exhibiting the power of the magnet, I first used our large battery of 20 pairs of plates, each 2 feet square, and afterwards a Wollaston battery, containing 280 pairs of 4-inch plates. When the opposite extremities of the seven thick wires were connected with the opposite ends of the battery of large or of small plates, we found it impossible to separate the keeper from the magnet by any force acting in a direction opposite to that in which the magnetic power was exerted. The keeper was a horse-shoe bar of iron about 20 inches long and 2½ inches diameter. The highest point of the arc formed by the keeper was 7 inches. The distance between its poles was the

pushed these roads into the very bosom of the wilderness. Like the military roads of the Romans, they hold steadily and straight on through plain and morass, through lane, forest, and river, and across the rugged Alleghanies, and the wild woods that skirt the banks of the Mohawk; and where a few years since an Indian hunter could scarcely force his way, you now dash along at the fearful velocity of twenty miles an hour. Many of these roads have been finished for less than 5000 dollars a mile; the very best of them made of English iron, and laid down on stone sleepers, have been completed for 29,000 dollars a mile, or about 6000*l*., which is only one-seventh the cost of the Liverpool and Manchester. The same method and dexterity which marks their steam-boat travelling, is also seen here: the engines are nearly all of American construction, having superseded those imported from England, and the engineers seem to have them under better control. There is certainly no unnecessary expense about these railroads. The sleepers are often not filled up, and frequently, in passing a deep chasm, or rushing torrent, the bridge is only just wide enough for the rails. Most of these railroads are at present single tracks, which occasion delay when trains meet. The carriages are larger than ours, they are sometimes fifty feet long, and have a deck with verandas. I have often remarked, that American engineers seem more dextrous than English. I have seen a train going seventeen miles an hour stopped in forty yards. The engine carries a large shovel in front, which removes any obstacle lying on the rail. Riding on the engines of a Washington train at night, I saw a cow lying on the rails; before I could exclaim, we were upon her, and I expected a shock, instead of which, the shovel picked her up, carried her a few yards, and then threw her to the roadside, out of the way. I took many opportunities of riding on the engines—wood is burned in most of them—anthracite coal in few. Their cylinders are mostly horizontal, like our own; but I saw several where the cylinders were vertical. There is a fine road from Albany, on the Hudson, to Utica, ninety miles. This road in a few months will reach to Buffalo, on the lake Erie, and then a traveller may pass from New York to Niagara, in twenty-four hours. There are railroads throughout all the New England States to every town of importance, and some thousand miles in progress in the South and West. There is the least improvement in the slave States. There is no country where you can cross such vast tracts in so short a time as in America, and the facilities are every day increasing. The Ohio already joins the Delaware, by a railroad 350 miles long, and in a few years, a traveller may be able to pass from the Gulf of Newfoundland to the Gulf of Mexico—from icebergs to orange-groves—in six days.—*Leicester Mercury*.

DESCRIPTION OF THE MOST POWERFUL ELECTRO-MAGNET YET CONSTRUCTED. BY THE REV. N. J. CALLAN, PROFESSOR OF NATURAL PHILOSOPHY IN THE R. C. COLLEGE, MAYNOOTH.

(From Sturgeon's *Annals of Electricity* for July).

I have lately constructed for the College, an electro-magnet which far surpasses in electric and magnetic power, all the electro-magnets of which I have been able to find a description. The iron bar of our magnet weighs 15 stone; it is 2½ inches in diameter, and more than 13 feet in length. It is bent into the form of a horse-shoe: the distance between the poles is 7 inches. A copper wire, one-sixth of an inch diameter, is coiled once round the whole length of the iron bar. This wire is divided into seven parts, each about 70 feet long. A thin copper wire, about one-fortieth of an inch in diameter, is soldered to one of the thick wires at about a foot from one of its extremities. The thin wire is about 10,000 feet long; it is wound round the magnet in the same direction as the thick wire, and in one continuous coil. By connecting the opposite ends of the seven thick wires with the opposite poles of a powerful galvanic battery, an extraordinary magnetic power is communicated to the iron bar; and, by breaking battery communication, an electric current of enormous intensity is excited in the long coil of thin wire. I have tried the magnetic and electric powers of this magnet only once. In consequence of making the trial, in presence of about 300 of the students, I was compelled to omit many of the experiments which I intended to make, and which I expect to make before the end of this month.

In exhibiting the power of the magnet, I first used our large battery of 20 pairs of plates, each 2 feet square, and afterwards a Wollaston battery, containing 280 pairs of 4-inch plates. When the opposite extremities of the seven thick wires were connected with the opposite ends of the battery of large or of small plates, we found it impossible to separate the keeper from the magnet by any force acting in a direction opposite to that in which the magnetic power was exerted. The keeper was a horse-shoe bar of iron about 20 inches long and 2½ inches diameter. The highest point of the arc formed by the keeper was 7 inches. The distance between its poles was the

important electrical researches, has recently invented an induction coil, which, though not more than five inches long, gives off a spark of four inches. He is pursuing the investigation in the hope of arriving at a combination of short coils from which to draw sparks of twenty or twenty-four inches in length, even with a small battery. He shews that iron-wire, though inferior to copper, is suitable for secondary coils, and thinks it better to strive for the production of long sparks than the employment of a long wire.

wards let them be put together, and the process of magnetizing be performed repeatedly upon each by the rest; and it will be found that each magnet possesses nearly, if not quite as much magnetism as the one employed in the first instance, that is, as the prime motor itself. This fact can scarcely be doubted, although it is at variance with the Newtonian law of the perfect equality of action and reaction as applied to mechanical forces, as no force can be supposed capable of generating under the same circumstances a force greater than itself.

Again, suppose we consider caloric as a moving force; what relation is there between that which is required to ignite a quantity of gunpowder and the caloric developed by its combustion? Several similar instances might be adduced of the inapplicability of the Newtonian law to the explanation of obscure physical facts.

LXXXVIII. *On a new Galvanic Battery. By the Rev.* N. J. Callan, *Professor of Natural Philosophy in the College of Maynooth.**

The following paper describes a new galvanic battery, consisting of 20 zinc and as many double copper plates, the whole of which may, by substituting one mercury trough for another, be made to act as a single pair of plates, or as 2, 3, 4, 5, 6, 10, or 20 voltaic circles; and which is capable of producing, by the aid of an electro-magnet, a voltaic current equal in intensity to that of a battery containing 1000 pairs of zinc and copper plates.

Under my directions, and on a plan suggested by me, a very large galvanic battery has been lately constructed for the College of Maynooth. This battery consists of 20 zinc plates, each two feet long and two feet broad, and of as many copper cells, each sufficiently large to contain one of the zinc plates. To each zinc plate is soldered a copper wire about half an inch thick and six inches long. The wire projects from the plate in a direction nearly parallel to the sides, and nearly perpendicular to the edge of the plate, which is vertical when the plate is in its copper cell. At two inches from its extremity the wire is bent so as to form nearly a right angle at the bend, and so that these two inches are parallel to the vertical edge of the plate. A wire of the same thickness, and about two inches shorter, is soldered to each of the copper cells: it is bent in the same way as the wires belonging to the zinc plates.

* Communicated by the Author.

Fig. 1.

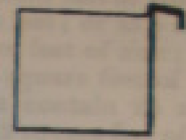
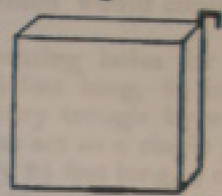
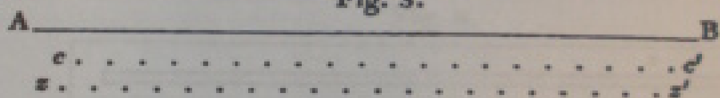


Fig. 2.



Figures 1 and 2 represent a zinc plate and a copper cell along with the wires soldered to them. The 20 copper cells are put into a wooden box about 3½ feet long, 2 feet 2 inches deep, and nearly 3 feet wide, and are separated from each other by partitions of wood. The 20 zinc plates are let down into the copper cells, and are lifted up, at pleasure, by means of a windlass. To prevent the contact of the zinc plates with the copper cells, each zinc plate is covered with a woven net of hemp. When the 20 copper cells are in the wooden box, and the 20 zinc plates in the copper cells, the wires soldered to the copper cells project about ¾ of an inch from one of the sides of the box, and their extremities descend nearly 2 inches below the upper edge of the same side: but the wires soldered to the zinc plates project nearly 2 inches from the same side of the box, and their extremities descend as low as the extremities of the wires belonging to the copper cells. Thus, if A B (fig. 3.) in the exterior surface of one of

Fig. 3.



the sides of the box be parallel to the upper edge of the same side, and nearly 2 inches below it, then the row of points *c c'* will represent the extremities of the wires belonging to the copper cells, and the row of points *z z'* will represent the extremities of the wires soldered to the zinc plates.

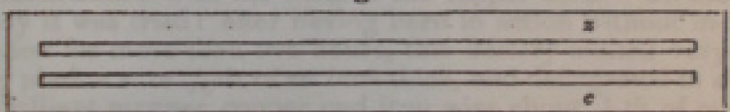
The acid solution is poured into the copper cells, which are water-tight, and is let out, without lifting the cells, by means of a cock at the bottom of each cell. The cells are barely wide enough to allow the free ascent and descent of the zinc plates. About 30 gallons of fluid are required to charge the whole battery. Both sides of each zinc plate are exposed to the action of the acid mixture, and are within about a quarter of an inch of an equal and parallel surface of copper. Hence the acting surface in each plate is 8 square feet, and the acting surface of zinc as well as of copper in the whole battery is 160 square feet.

By eight mercury troughs, metallic communications may be formed between the 20 zinc plates and the copper cells, so as to make the whole act as a single pair of plates, each containing 160 square feet of surface; or as 2 voltaic circles, in which

the zinc of each circle would contain 80 square feet; or as 3 circles, two of which would contain 56 square feet of zinc, and the third of which would contain 48 square feet; or as 4 circles, in each of which there would be 40 square feet of zinc; or as 5, in each of which there would be 32 square feet of zinc; or as 6 circles, four of which would each contain 24 square feet, and two of which would each contain 32 square feet of zinc; or as 10 circles, in each of which there would be 16 square feet of zinc; or as 20 circles, each of which would contain 8 square feet of zinc.

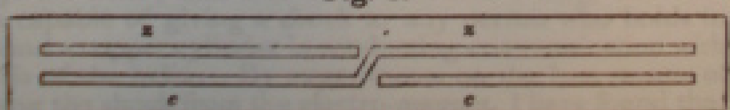
The mercury troughs are made by cutting holes for containing mercury in a piece of wood $3\frac{1}{2}$ feet long, $3\frac{1}{2}$ inches broad, and 2 inches thick. The mercury trough by which all the zinc and copper plates are made to act as a single pair, contains two parallel grooves, each nearly $3\frac{1}{2}$ feet long, $\frac{3}{4}$ of an inch wide, and an inch deep. One of the grooves receives all the wires of the zinc plates, and the other receives all the wires of the copper cells. Hence when mercury is poured into the two grooves, all the zinc plates are in metallic communication with each other, and act as one plate; and all the coppers likewise act as one copper plate. This trough is represented in fig. 4.; the letter *z* shows the groove for the wires of

Fig. 4.



the zinc plates, and *c* the groove for the wires of the copper cells. In the second mercury trough there are four grooves, each of which receives 10 wires. There is a communication between one of the grooves containing the wires of ten copper cells, and that which receives the wires of the zinc plates immersed in the remaining 10 cells. Fig. 5. represents this

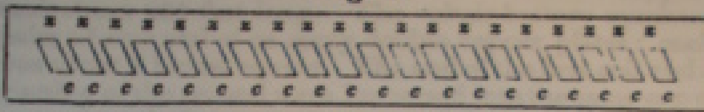
Fig. 5.



trough. The third trough contains 6 grooves; the fourth, 8; the fifth, 10; the sixth, 12; and the seventh and eighth each contain 20. Except the trough by which the battery is made to act as 20 voltaic circles, the rest are made like the trough represented in fig. 5. When the battery acts as 20 circles, the wire of each zinc plate, and the wire of the next

copper cell, are in the same mercury hole. Fig. 6. represents

Fig. 6.



the upper surface of the trough by which all the zinc and copper plates are made to act as 20 circles.

From the preceding description of our battery, it is evident that the whole 20 zinc plates and copper cells may, by substituting one mercury trough for another, be made to act as a single pair, or as 2, 3, 4, 5, 6, 10, or 20 voltaic circles, and thus be made to supply the place of the calorimotor and of the battery hitherto used for electro-magnetic experiments.

So enormous is the quantity of electricity circulated by this battery when all the zinc and copper plates act as a single circle, that, on one occasion, after having acted without interruption for more than an hour, it rendered powerfully magnetic an electro-magnet on which were coiled 39 thick copper wires, each about 35 feet long, while the mercury in which the wires of the zinc plates were immersed, was connected by 6 copper wires, each $\frac{1}{5}$ of an inch thick and about 6 inches long, with the mercury in communication with the wires of the copper cells. On the fifth day it was tried: after having been in action without interruption for more than two hours, this battery melted very rapidly platina wire $\frac{1}{30}$th of an inch thick, and deflagrated in a most brilliant manner copper and iron wire about $\frac{1}{12}$th of an inch thick.

By this battery, with the aid of an electro-magnet, a current of electricity may be produced which will equal in intensity that of a battery containing 1000 voltaic circles. It is well known that when the connexion between the helix of an electro-magnet and the voltaic battery is broken, a current of electricity is, at the moment of breaking the connexion, made to flow through the helix; and that when the helix is long, that current is capable of giving a shock to any person who holds in each hand a copper cylinder in conducting communication with the ends of the helix. By experiments on the best means of obtaining the shock from the electro-magnet, I have found that the shock increases, within certain limits, with the length and thinness of the bar of soft iron, and with the length of the heliacal coil, as far perhaps as 200 feet, and in proportion, or nearly in proportion, to the number of plates in the voltaic battery from which the current of electricity is passed through the helix. The shock does *not* increase in proportion to the number

of plates unless they are large. The electro-magnet which I first used was a straight bar of soft iron, about 2 feet long, and an inch thick. On this bar were coiled two copper wires, each about 200 feet long. The voltaic battery consisted of 14 pairs of zinc and of as many double copper plates: each plate was about 7 inches square. The end of the first coil and the beginning of the second were immersed into the same cup of mercury, the voltaic current was passed through the first coil only, and the shock was taken by making a communication with the beginning of the first coil and with the end of the second. When the current of electricity was passed through the helix from one pair of plates, the shock received on breaking contact with the battery was equal to that of a battery containing 20 pairs of plates. When two pairs of plates were used, the shock appeared to be doubled; with three voltaic circles, it appeared to be trebled; and with every increase in the number of voltaic circles, there appeared to be a proportional increase of the shock. With the 14 pairs of plates the shock was so strong that a person who took it, from an electro-magnet on which there were four coils of wire, felt the effects of it for several days. With a battery of 4-inch plates the shock increased with the number of plates, but not so rapidly as when large plates were used. I am inclined to think that with a battery of 4-inch plates, the shock increases but little when the number of plates exceeds a hundred. I could not induce any one to take the shock from the electro-magnet when a greater number than 16 of our large plates were used. With 16 of them the shock was exceedingly strong, although the acid mixture employed in charging the battery was very weak; and, from experience, I know that the electro-magnetic effects of a battery depend very much on the strength of the charge.

From all the experiments which I have made on the magneto-electric shock, I think I may fairly conclude, that, if 2000 feet of wire were coiled on a bar of soft iron 6 feet long and an inch thick, a shock might be obtained with the aid of a single pair of plates, which would equal that of a battery of 100 voltaic circles. Hence, since the shock increases in proportion to, or, at least, very rapidly with the number of plates, when they are large, the shock given by such an electro-magnet magnetized by our battery of 20 pairs of plates, should nearly equal, or perhaps exceed that of a battery of 1000 voltaic circles. Hence, by our battery of 20 pairs of plates, an electric current of the highest intensity may be produced. This battery then supplies the place of all the various kinds of galvanic batteries.

The shock given by the electro-magnet may be obtained

as often as the connexion of the helix with the battery is broken. Now I have devised a small instrument by which communication with the battery may be broken and renewed 3000 or 4000 times in a minute. Thus 3000 or 4000 shocks may be received, and 3000 or 4000 electric currents of the highest intensity may, in the space of one minute, be passed through water, charcoal, metallic wires, or any other body. It should be remembered that the voltaic current from the battery should not be passed through more than 200 feet of the helical coil, and that the shock should be taken from the whole length of the helix.

When a voltaic current passes through a very long wire from a single pair of plates, the wire will give a shock at the moment of breaking contact with the battery. I have found that this as well as the shock from the electro-magnet increases with the number of plates.

I have made a great variety of experiments on electro-magnets. My object in these experiments was to ascertain four things: first, on what the quantity of attraction depends; secondly, on what the distance at which that attraction is exerted depends; thirdly, on what the shock depends; and fourthly, whether by a voltaic current from a large battery, a permanent magnet could be made, which would induce on soft iron magnetism equal to that which is given to an electro-magnet by a battery containing 20 large plates, or 300 four-inch plates. In these experiments I employed three different voltaic batteries, and electro-magnets of various forms. I used the large battery already described; a small battery of 14 pairs of plates, in which each zinc plate was seven inches square; and a Wollaston battery, containing 280 pairs of four-inch plates. Some of my electro-magnets were straight, and others of the horse-shoe form, and one was a square: the iron bars varied in length from 20 inches to six feet, and in thickness from two inches to half an inch. On one of these were coiled 39 copper wires, on another four, on a third three, and on others there was only one wire.

From the results of these experiments, I have deduced the following conclusions: First, that the quantity of attraction increases with the length of the bar of soft iron, at least as far as six feet, and with the thinness till it becomes about an inch; and that it increases nearly in proportion to the number of plates (when they are large) in the battery by which the electro-magnet is magnetized. When the plates are only four inches square the attraction increases, but slowly when the number exceeds 100. Secondly, that the distance at which attraction is exerted, increases also with the length and thickness of the

iron bar, and with the number of plates when they are large; but with small plates the increase is very gradual when their number exceeds a hundred. With twenty of our large plates, an iron bar, nearly 3½ lbs. weight, was attracted to a horse-shoe electro-magnet through the distance of an inch, and with ten plates the same bar was attracted to the same magnet, only through the distance of about half an inch. Again, with the twenty plates, the attraction of the same magnet for a sewing-needle was sensible at the distance of 15 inches, and with ten plates the attraction was sensible at the distance of 10 inches. Thirdly, that the shock from the electro-magnet increases within certain limits with the length and thinness of the iron bar, and nearly in proportion to the number of plates when they are large.

When the voltaic current was sent from a battery of 280 four-inch plates, through the heliacal wire coiled round a steel bar about 20 inches long and an inch thick, the steel became almost as strongly magnetic as if it were iron; and when the connexion with the battery was broken, the steel did not retain more than about $\frac{1}{100}$ of its magnetism.

In a paper published in the last (August) number of the Philosophical Magazine, Dr. Ritchie says that the use of the electro-magnet in the apparatus for continued rotation was long since abandoned, because it was incapable of inducing magnetism in an iron bar at a distance. Now he will find that, if instead of a single copper and zinc plate, a battery of 20 pairs of large plates, or of 200 small ones be used, the electro-magnet will have a greater power of inducing magnetism at a distance than any permanent magnet.

The advantages of the battery I have described are, first, that it supplies the place of all the various kinds of voltaic batteries, of the battery for producing a large quantity of electricity of low intensity, of the battery for exciting a large quantity of electricity of the intensity necessary for the rapid fusion and deflagration of metallic wires, and of the battery for producing an electric current of high intensity; and secondly, that it enables a person to compare the power of the very same zinc and copper plates acting as a single pair, with their power when they act as 2, 3, 4, 5, 6, 10, or 20 voltaic circles.

NICHOLAS CALLAN.

Maynooth College, August 23, 1836.

XLII. *On the Stratification of Electric Light.* *By the* Rev. T. R. Robinson, *F.R.S. &c.*[*]

[I]N a communication on the Stratification of Electric Light in rarefied Media, which appeared in the Philosophical Magazine [of] last July, Mr. Grove has described some facts which are in close [rela]tion to the cause of that phænomenon, of which the most [imp]ortant is this—If in the circuit of an induction-machine of [whi]ch an exhausted vessel forms a part, there be an interruption [whi]ch is gradually lessened till sparks just pass it occasionally, [the]se sparks are blue, and have a single sharp sound; if the [inte]rval be still more diminished, they become yellow, burred, [and] their sound is not so clear, but is attended with a slight [bu]z. Now he finds that the blue sparks do not form strata [in t]he vacuum, but that the yellow do, so that by regulating [the] distance he can produce them or not at pleasure. He *thinks* [the] blue are single, and the yellow double or multiple; and finds [in t]his a proof of his former opinion, that these strata are caused [by] some peculiar action of compound discharges. Within the [last] few weeks he has developed these views more fully in a lec[tur]e at the Royal Institution.

[E]verything which comes from Mr. Grove bears the stamp of [sag]acity and power; and I read this paper with great interest; [but] circumstances prevented me till recently from repeating its [exp]eriments. The results which I have obtained, show that its [lea]ding inference cannot be received as universal; for, *in the cir[cum]stances of my experiments,* I always obtained strata when a spark [pas]sed, whether long or short, blue or yellow. Any one versed [in] these inquiries knows how much the strata are modified by [sli]ght variations of apparatus, &c.; and some such have probably [cau]sed this discrepancy; I will therefore describe mine in some [det]ail.

[T]he induction-machine which was mostly employed, consists [of] six sectional coils (the gift of my friend Dr. Callan), each con[tai]ning 8000 feet of fine iron wire, not lapped, but insulated by [an] elastic varnish. They are arranged, three on each of two [iden]tical primaries, having each 350 spires of No. 12 copper, and [cor]es of iron No. 17. Their internal terminals are below, con[nec]ted in the centre; and the current is passed collaterally [thr]ough the primaries, so that the external terminals of the ex[tre]me coils have equal and opposite tensions. The condenser [ha]s 100 square feet of charged surface, which can be used in [por]tions of 20 according to the battery power. The rheotome is [mer]curial†; and the machine gives sparks of about one inch [for] every Grove's cell used to excite it. A few words respecting

[*] Communicated by the Author.

† This kind of rheotome is the best which I have tried, giving sparks

these sparks may be found relevant to the present question. If the terminals be connected with a spark-micrometer opened to about twice the striking distance, when the machine acts, a lucid star will appear on one or both points. Bringing them gradually closer, a small brush, exactly like that produced by a point on a prime conductor, is seen at the positive point: as the distance is lessened, the filaments of this brush extend, and at last curve towards the negative with a sputtering sound. Still nearer, and sparks strike across with an intense light and sharp snap which cannot possibly be mistaken for the preceding form of discharge: they are zigzag; and, when the excitation is powerful, two-thirds of their length at the positive end is often red, the rest bluish white. If the distance be less, the spark has that strange yellow envelope which, as Du Moncel has shown, can be blown aside like a flame, but which is certainly not a second discharge*. And at very short distances there is sometimes a sheaf of curved sparks between the points. If one terminal be connected with the gas-pipes of the house, and the arm of the micrometer which had been joined to it be connected with the floor (so that the circuit includes a very great resistance), we obtain what is called the static discharge, which is of the same character as the inductive one discovered by Mr. Gassiot, and, like it, can be distinguished from the dynamic one by the magnet when passing through a vacuum and the revolving mirror in air: it is about half the length of the other. The vacuum which I included in the circuit was an "electric egg," 9′ high and 6′ diameter; on its wires were cemented glass tubes with Wollaston's points of platinum, $\frac{1}{50}$ diameter, 6′ apart. This form of electrodes reduces the conditions of discharge to a more definite state than when they are balls or naked wires; and the following may be considered its normal character when the egg has been filled with dry hydrogen and exhausted to 0′·08. Supposing the upper electrode positive, there is at it a brilliant

whose length is 1·3 times that of those obtained by the spring rheotomes of Hearder or Ladd: Ruhmkorff's vibrating hammer is much feebler. This very energy, however, tests the insulation of the coils severely. I find two precautions necessary in using it:—(1) the mercury must be negative, otherwise the action is almost explosive, and the effect only [illegible]; (2) the platinum points should work through a diaphragm of thin vulcanized rubber, to prevent the blackened alcohol from being splashed about.

* When such a spark is viewed in a revolving mirror, its thickness is slightly increased, but the envelope is drawn out into a sheet extending many degrees, even when the rotation is comparatively slow, which shows that it lasts much longer than the spark itself. This explains a singular fact which has occurred to me occasionally. In a hydrogen vacuum =2′·50, if a small Leyden jar be connected with the machine, according to Mr. Grove's plan, the discharge passes as a splendid scarlet spark; this is sometimes surrounded by a faint elliptic envelope, which continues visible for 0″·1 after the other has disappeared.

oint, from which streams an elliptic spindle of greenish light r about two-thirds of the distance, brightest in the axis: is is full of strata, thick near the point and curved round it e spheric shells, thinner below and less curved, till at the lower rmination of the positive light they are nearly plane and only ·05 or 0′·06 thick. In the bright central portion they seem icker than their continuations into the surrounding part, hich are also bent back abruptly. If the excitation be very owerful, the curvature of the lower strata is reversed, these eing in that case formed, as Mr. Gassiot has shown, by that urrent which passes on closing the primary circuit. Below the ositive light is a dark space from 0′·5 to 2′ wide; and lower ill is an atmosphere of bright blue light (which I call the igrette). It is generally conical with a convex base, *never hows strata,* but seems to be composed of rays diverging from he negative point. From this, however, it is separated by thin dark space surrounding it like a wrapper, and within hat by a reddish-violet one. Along the glass tube, below this, ositive light with its strata reappears; due probably to the dif-iculty of insulating the wire where the tube ends. If static ischarges be passed, the appearances *at each point* are similar— negative aigrette, a dark space, and a few thick spherical strata t each end of the faint spindle of light concave towards the earest point. This is explained by the double nature of this lischarge. If a static spark be viewed in the mirror revolving ighty times in the second, it is seen to consist of two, the econd narrower than the first and less luminous, about 5° ehind it, that is, nearly $\frac{1}{5000}$th of a second later: the two being pposite in direction, produce two reverse systems, which are nerely superposed.

Having premised so much, my trial of Mr. Grove's experiment an be easily described. Exciting the induction-machine by two Grove's, it gave static sparks = 0′·90, and dynamic = 2′·227 at the rate of 7 in 2ˢ. With the egg in circuit, no sparks passed till the micrometer was at 1′·038. During the whole of the previous star- and brush-discharges, the appearances in the egg were those which I have described as static, strata and aigrettes *at each* end, even when the micrometer was at 4′. The moment a spark passed (and, as I have already said, these cannot be mistaken), the strata appeared in their normal condition, merely increasing in brightness and magnitude till the micrometer was in contact. By no manipulation of it or the rheotome could I get a spark without producing them; nor, indeed, could I get any discharge through the vacuum without getting at least the static set.

On another occasion with three Grove's, the static spark was

02 and the other 2′·925; but, as before, I could get no *dis-ge without strata.* Then I examined the sparks, which were ıally showing them splendidly, in the revolving mirror at the ıest speed which I could manage, 120 in a second. There have been a few multiple, but only as exceptional; for in ost every instance they were certainly single with that speed, ch would easily show $\frac{1}{20000}$ of the second. I substituted the egg one of Mr. Gassiot's magnificent Torricellian tubes which, as well as much precious information and personal lness, I have to thank that gentleman). It is 1′ diameter, 31′·3 between the platinum points: whenever a spark passed micrometer, its peculiar strata appeared in their normal ıty; but with the brush, they had the peculiar character ch Mr. Gassiot has shown to belong to discharges made by ıction through the glass; and placing the tube axial on a erful electro-magnet, it showed, as in his trials, the brush harges to be double in opposite directions, or, as he calls n, "reciprocating."

hese are not the only trials which I have made; but I inva-ly found that no length of spark prevents the formation of ta, and I am obliged to conclude that Mr. Grove's rule is absolute. The difference between our results depends btless on some unnoticed difference in the conditions under ch we operated. Among possible causes may be named the nature of the vacuum. He used air with phosphorus our diffused in it; I hydrogen: I prefer that, as definite in ıre, as with equal air-pumps giving a rarefaction fourteen s greater, and as exhibiting these strata better than any ium with which I am acquainted, except mercurial vapour. The sort of electrodes. Believing the strata to depend on a ıliar mode of disruptive discharge, I think they will be ıed most certainly when the electric power is concentrated a narrow area, as in the guarded points which I used. The direction of the current. When the upper electrode is tive, they are better developed than when it is negative; in latter case there are often only a few large ones near the r point, and the rest are lost in luminous haze, the ascend-currents of the heated medium probably confusing them. Still more important is the intensity of the electricity: with weak power (which would give an air-spark of 0′·1 or 0′·2) ve failed in obtaining them, even in the Gassiot tube. On other hand, excessive power fails also, but in a different way, lucing but concealing them. If, when my six coils are ly charged, the discharge of one, two, &c. be passed in suc-ion, it is seen that the bright strata throw out cloudy ap-lages into the dark intervals as the intensity increases, so

at with one giving 5′ sparks, the latter are filled with light. Mr. Gassiot found the same effect from increasing the number of battery cells; and I believe that his gigantic American machine scarcely shows any stratification.

But even were it universally true that a spark of sufficient length interposed in the circuit prevents the appearance of strata, still Mr. Grove's theory of their origin would remain subject to weighty objections. We have no experimental evidence that the current which he supposes to succeed the extra current in the primary coil, exists with any sensible energy; and, granting its existence, it is not easy to see how it can produce the effects assigned to it; for, apparently, it must be *subsequent* to the discharge of the secondary coil, and therefore cannot modify that in any way. A synchronous one, we know from experiment, only weakens the force of another that is opposite; and in the static discharge, where there is the very system which he requires, a discharge followed at a very small interval by a weaker opposite one, there is certainly no special power of developing strata.

A different view of their origin, and one which seems nearer the truth, is given in the Number of 'Cosmos' for the 4th of last month, by M. Morren of Marseilles. He thinks they are caused by periodical variations of intensity in the current, due to the resistance which it meets in traversing an imperfect conductor, and that these cause lateral discharges of the conducting material; he therefore compares them with the wings that project from the stains made by exploding fine wires over paper by an electric battery. The notice is so brief, that I supposed he meant to represent these explosion-pictures as "autographies des stratifications de la lumière électrique;" but the meaning of this phrase is made clear by another notice in the same journal (Feb. 18) from M. Seguin, who also seems to have obtained the same result. An induction spark sent along glass dusted with fine charcoal, leaves a track whose markings he considers identical with the strata. Undoubtedly these variations of intensity do exist: they are shown by the fracture of a wire into minute pieces when the discharge is not quite sufficient to fuse it, and still more plainly by sending the static discharge of a powerful induction machine through a fine steel wire some feet long. In air of ordinary density, and still more in rarefied air, the wire is luminous; but at every inch or two it throws out a circle of brushes. In the exploded wire, or the air over the glass, the same thing happens; but the brushes carry with them most of the metallic vapour or the charcoal dust, leaving a deficiency of them at the intermediate points. On repeating M. Seguin's experiment, I obtained the appearances which he describes:

they have a strong resemblance to the explosion-pictures, and also to the yellow envelope already referred to as surrounding short sparks; but, as it seems to me, their analogy to the strata is far from complete. The transverse divisions scarcely ever go entirely across, and have no regularity; the jagged fringes and serrated points which form the outline, are in strong contrast with the smooth and comparatively definite boundary which the light often shows; but, above all, the markings extend through *the whole* track of the discharge, and there is nothing analogous to the dark space or the blue negative light. In fact the two sets of phænomena seem to belong to different categories: one is the transfer of matter laterally from the axis of discharge by a vehement repulsion; the other is a succession, along a certain portion of that axis, of fits of discontinuity in the light-producing power of the current. That power, for a certain further distance, totally ceases, to reappear without any intermission, and with the development of rays of higher refrangibility. It is certainly possible that, in rarefied air, these so-called autographs might assume a similar character; but unless this prove to be the case, I think it will be felt that some further step is necessary to complete the explanation. As it now stands, any one who compares a fine set of strata with (for example) the superb drawings of exploded wire in Van Marum's *Description d'une très-grande machine Electrique*, will scarcely admit them to be results of the same action, that of mere repulsive force.

It has been for some time my own opinion that the strata are caused by these periods of intensity, but in a different way from that just mentioned,—by the successive zones along the axis becoming charged up to the point of disruption. I feel, however, that any exposition of it must be premature till more facts are collected, and still more till we have a mathematical investigation of a current's motion in an imperfect conductor. While such labourers as Faraday, Gassiot, and Grove himself are in the field, we can have little doubt that the harvest will not be long unreaped; and we may surely expect that some powerful mind will ere long bring within the domain of analysis the hypothesis (which every day confirms) that electricity is, as Grove expresses it, "a mode of motion." Such an investigation is, from its correlation to other molecular forces, of the highest importance, and will certainly reward most amply its author.

Armagh Observatory, March 7.

ness were less than this, the resultant of the cohesive force would be less, and the crust would crack at some intermediate point.

Every physical consideration seems to indicate that the crust must be very thick; and the only real calculation of its limiting thickness on physical principles, viz. that of Mr. Hopkins, should be received.

The form the surface at present exhibits may be supposed to have arisen from the contraction and expansion of the parts of this thick crust since it first began to form, producing hollows in which seas and oceans have gathered together their waters, and elevations in continents, table-lands, and mountains; and therefore the variations of the surface, under its present aspect, are not at all regulated or produced by hydrostatical principles.

J. H. Pratt.

Calcutta, Feb. 22, 1859.

LII. *A brief Account of an Induction Coil of great power in proportion to its length.* By the Rev. N. J. Callan, D.D., *Professor of Natural Philosophy in Maynooth College*.*

In the construction of induction coils, the principal object of some seems to have been to make the coil in such a way, that with a given length of secondary wire the longest sparks may be obtained. It appears to me that it would be better to make induction coils so that, with a given battery, sparks of the greatest length may be produced. The longer the coil is, the greater will be the resistance of the primary wire to the current of the battery, and the greater the number of cells which will be required to overcome that resistance and saturate the core with magnetism. Hence it is a matter of great importance to make coils in such a way that, whilst they are short, they may produce very long sparks. I have endeavoured to do this; and though the primary and secondary coils of the induction coil I have made are very imperfect, I have succeeded tolerably well.

The primary coil is made of thick copper wire about 140 feet long: it is 10 inches in length. The conducting power of the copper wire was injured by being frequently coiled on electro-magnets, or on cores of induction coils.

The secondary coil consists of three small coils: two of them are $1\frac{3}{4}$ inch long, the third is only $1\frac{1}{2}$ inch. Hence the entire length of the secondary coil is 5 inches. It is only half the length of the primary coil, and is therefore not finished. The secondary coil is made of iron wire, No. 34 gauge; the thickness of the wire is about the $\frac{1}{100}$th of an inch. The wire is covered only partially with cotton thread. Between each two ad-

* Communicated by the Author.

joining spirals of the thread wound on the wire, there is sufficient room for another spiral of thread, and on a great part of the wire there is space enough to admit three or four threads. I adopted this mode of covering the wire in order to save time. With the same view, I arranged our machine for winding thread on wire so that by one and the same operation I covered the wire with thread and wound the wire on the coil. I fear that in many parts of the coil the bare or uncovered part of one wire is in contact with some parts of the adjoining wires. Each layer of spirals is brushed over with a hot solution of gutta percha dissolved in rosin oil. The solution is so thick, that when cool it takes the form of a paste. Each layer of spirals is insulated from those of the layer above and below it by paper saturated with the solution of gutta percha, in the manner described in the paper which I read at the Dublin Meeting of the British Association in 1857, and which was published in the Philosophical Magazine for the following November. I have in one instance seen sparks passing through the three thicknesses of paper, by which the spirals in one layer are insulated from those of the one above it. Hence the insulation of each layer of spirals from those above and below it is defective.

In trying the two parts of the coil which were first made, I observed, as often as sparks passed between the terminals of the coil, a great number of very minute sparks on the outside of one of the two parts. This made me suspect that these sparks were passing from some spirals to the adjoining ones. When I had finished the third part of the coil, I abstained from brushing over the outside spirals with the solution of gutta percha, in order to see whether sparks would pass from one spiral to another. As soon as the battery was connected with the primary coil by means of our mercurial contact-breaker, sparks passed from the bare parts of several wires to the contiguous ones. When any part was brushed over with the gutta-percha solution, the sparks ceased there, but became more numerous in some other part.

This coil, though only 5 inches long, has, notwithstanding all its defects, given sparks $4\frac{1}{2}$ inches in length with three cells of the Maynooth battery, each 4 inches square. I have not seen an account of any coil which with so small a battery has given sparks so long in proportion to the length of the coil. On account of the imperfect insulation of the secondary coil, I am afraid to use a more powerful battery.

I intend to make a new primary coil about 36 inches long, and twelve small secondary coils, each about 2 inches in length. From this coil I expect to get, with a small battery, sparks 20 or 24 inches long.

I have made several interesting experiments on the various

parts of the coil, which I have not time at present to describe. Many more remain yet to be made. When they are finished, I shall prepare an account of them for publication in the Philosophical Magazine.

My object at present is, first, to show that iron wire, though far inferior to copper in conducting power, is not unfit for secondary coils; secondly, to direct attention to the importance of making induction coils so that with a given length, not of the secondary wire, but of the coil, the longest sparks may be produced; and thirdly, to show that a mere covering of the secondary wire with thread of any kind is not sufficient to insulate the spirals of any layer from the adjoining ones of the same layer.

Maynooth College, April 4, 1859.

LIII. *On a New Form of Telegraph Cable intended to reduce the effects of Inductive Action.* By J. N. Hearder, *Electrician, Plymouth**.

IN my last paper I described the nature of the inductive action which takes place during the transmission of electrical currents through insulated submarine conductors, and pointed out the various disturbing influences which it occasions. It is now pretty well admitted by telegraph engineers, that, unless these impediments to the free and rapid transmission of signals can be either entirely removed or considerably lessened, the commercial value of very long lines will be somewhat in the inverse ratio of their lengths. As, however, the mechanical engineer has overcome the difficulty of laying telegraph cables, it now remains for the electrician to overcome the scientific difficulties which beset his path, and to render his line of communication thoroughly efficient after it is laid.

Of late much attention has been directed to the subject, and some very able communications from practical electricians have contributed to throw much light upon it. From the very first moment when the static charge of the gutta-percha coating was brought under my notice, I felt that it would one day act as a formidable barrier to the extension of submarine lines; and I saw at that time no chance of remedy, except in the employment of larger conductors and thicker insulating coatings. Within the last year or two, plans have been proposed to reduce the amount of induction, some of which appear to be founded upon an incorrect apprehension of the electrical phænomena to which such arrangements would give rise. For instance, it has been

* Read at the Plymouth Institution, March 3, 1859. Communicated by the Author.

THE

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PHILOSOPHICAL MAGAZINE

AND

JOURNAL OF SCIENCE.

[FOURTH SERIES.]

JUNE 1863.

LVI. *On an Induction Coil of great power, and on the effects of connecting Plates with the ends of the Secondary Coil. By the* Rev. N. J. Callan, *D.D., Professor of Natural Philosophy in St. Patrick's College, Maynooth**.

ABOUT three years and a half ago I made an induction coil of considerable power. The secondary coil, which was made of No. 34 iron wire, consisted of three parts, two of which were each about 2½ inches, and the third 3 inches long. The entire length of the secondary coil was about 8 inches, and the length of the secondary wire about 150,000 feet. The mode of insulation is nearly the same as that of the coil described in the Philosophical Magazine for May 1859, except that thin sheet gutta percha is used for insulating the spirals of one layer from those of the adjoining layers. With three cells of the Maynooth battery, in each of which the zinc plate was 4 inches square, the coil gave sparks about 10 inches long between two pointed wires, one connected with each end of the coil. With five cells of the same size, the sparks were only 10¼ inches, but were much louder than the sparks produced by three cells. Within the last four months I made a new primary coil nearly 3 feet long with a core about 3 feet 6 inches in length, and improved the insulation between the secondary coil and the primary, and also the insulation of the three parts of the secondary from each other.

Since these changes were made, this coil (the negative end being connected with a plate containing a square foot of surface, and the positive end with a pointed wire) gave sparks 7½ inches long with a single 4-inch cell of the Maynooth battery. With two 4-inch cells the sparks were 12½ inches, and with three cells of the same size they were 15 inches in length.

* Communicated by the Author.

When the sparks were taken between two pointed wires, they were only 6 inches with one, and a little more than 13¼ inches with three 4-inch cells. Hence, when the negative end is connected with a plate a foot square, the sparks are 1½ inch longer with one cell and 1¾ inch longer with three cells than when each end of the coil is connected with a pointed wire.

When the negative end was connected with a circular brass plate 4 inches in diameter, and the positive with a pointed wire, the sparks with one cell were 6¼ inches, and with three cells they were 13¾ inches. Therefore when the negative end is connected with a plate a foot square, the sparks are 1¼ inch longer than when it is connected with a 4-inch circular plate.

Since I discovered the great increase produced in the length of the spark by connecting a large plate of any metal with the negative end of the coil, I made a series of experiments in order to ascertain the best size of the plate, and the effects of connecting plates in various ways with the ends of the coil. Some of the results of these experiments appear to be anomalous, and not in accordance with the commonly received theory regarding the distribution of electricity over the surface of bodies, nor with the rule for determining the height to which a lightning conductor should project above the roof of a building to which it is attached.

First, with regard to the size of the plate necessary to produce the longest spark, I have found that a circular metallic plate 7 inches in diameter is sufficiently large when the spark does not exceed 10 inches, and that a piece of wood 9 inches square produces the same effect as the 7-inch plate. I commonly use a circular plate of tin about 12½ inches in diameter. With this plate the coil gives a spark an eighth of an inch longer than with a plate containing four square feet of surface. In order to get the longest spark from a coil, the outer end of the secondary coil should be positive, and the inner end negative; the plate should be connected with the negative end, and the pointed wire with the positive end, and the central part of the plate should face the point of the wire. When the plate faces the point, and its circumference is opposite the point, the sparks are a little shorter than when the point is opposite the middle of the plate.

Secondly, with regard to the effects of plates connected with the ends of the coil, I have found that the effects of a plate in connexion with the negative end differ very much and in various ways from those that are produced by a plate connected with the positive end.

In most of my experiments on this subject the greatest length of spark the coil was capable of giving with the three cells em-

ployed varied from 13½ to 15 inches. When I used a weaker battery I mention the length of the spark. The plate was about 12½ inches, and the point was opposite to the middle of the plate, except when the contrary is expressed.

First, when a pointed wire is connected with the positive end of the coil, a plate connected with the negative end lengthens the spark considerably; but when the pointed wire is connected with the negative end, a plate connected with the positive one shortens the spark in a greater proportion. Sparks which were 15 inches long in the first arrangement were reduced to less than 11 inches by the second; they did not pass at all between the positive plate and negative point until the plate was brought within 8½ inches from the point.

Secondly, sparks from a positive point to a negative plate never went to the circumference of the plate, and scarcely ever struck the plate at a greater distance from the centre than 3 inches. But sparks between a negative point and positive plate always went to the circumference until the plate was brought within 2½ or 3 inches from the point: even when I used a rectangular plate 20 inches broad and 28 inches long, the sparks went to the edge of the plate.

Thirdly, the sparks from a positive point to a negative plate never moved in a straight line, even when the point was less than an inch from the plate. But when a negative point is brought within 2½ or 3 inches, or even less than an inch from a positive plate, the sparks pass in a straight line between the point and the nearest part of the plate.

Fourthly, the sparks from a positive point to a negative plate grow weaker and less loud as the point is made to approach the plate. But when a negative point is brought within two or three inches from a positive plate, the sparks become as loud as if the plate were charged, or as if they were produced by a small Leyden jar whose opposite coatings were connected with the ends of the coil. With a plate containing four square feet of surface, the sparks were louder than with the 12-inch plate. A hollow ball connected with the positive end of the coil also gives very loud sparks. Hence a plate or ball connected with the positive end becomes charged, but a plate connected with the negative end does not.

Fifthly, when a pointed wire nearly ¼ of an inch thick projected 6½ inches from the middle of the 12½-inch circular plate connected with the negative end of the coil, and nearly at right angles to the plate, and another plate of the same size was connected with the positive end, the sparks passed not between the point and positive plate, but from the circumference of one to the circumference of the other, although the distance of the point

from the plate was less than 4 inches, and the distance between the circumference of one plate and that of the other was 10 inches. But when a pointed wire projected more than three-fourths of an inch from the middle of a plate connected with the positive end of the coil, and the other plate was connected with the negative end, the sparks passed from the point to the negative plate, and never from the circumference of one to that of the other.

Sixthly, when a pointed wire projected from the negative plate at about half an inch from its circumference, and 3½ inches from the plate, the sparks passed even then far less frequently between the point and the opposite circumference of the positive plate than between the circumference of one and that of the other plate. But no such effect will take place when the pointed wire projects from the positive plate.

When a pointed wire projected 3½ inches from the middle of a wet slate about 9 inches square, or 2½ inches from the middle of a wet piece of wood of the same size, connected with the negative end of the coil, and the 12½-inch plate was connected with the positive end, the sparks passed between the circumference of the plate and the edges of the slate or wood, rather than between the point and plate. When the slate or wood is dry, the sparks passed from the pointed wire to the positive plate. When the wood or slate is merely damp but not very wet, the sparks from the wire frequently run to the edge of the slate or wood and then pass to the plate. If the wire project from the wood or slate near the edges, the sparks will pass between the point and positive plate, unless when the pointed wire projects to a small distance from the wood or slate.

A ball 3 inches in diameter connected with the positive end shortens the spark as much as a 12-inch plate.

When a pointed wire is opposite the edge of a plate connected with the negative end, the spark is longer than between two points, but shorter than between a positive point and the middle of a negative plate.

When two plates are connected with the ends of the coil and face each other, the spark is reduced from 15 inches to about 11 inches. When their edges are opposite to each other, the spark is also shortened.

I have repeated most of the above-mentioned experiments with a weak battery which gave sparks 7 or 8 inches long, and obtained the same results. When the sparks are about 8 inches, the plate connected with the end plate should not be more than 7 inches in diameter. When I connected the 12½-inch plate, or a 3-inch hollow ball, with the positive end (the longest spark being about 8 inches), no spark passed between the plate or ball and a negative point until the point was brought within about 2

inches from the plate, or until the sparks resembled the discharges of a small Leyden jar. The sparks never passed between the point and circumference of the plate. It was otherwise when I used a 7-inch plate. Hence the size of the plate connected with the positive end of the coil must depend on the power of the coil employed. The pointed wire used in all the experiments was nearly $\frac{1}{4}$ of an inch thick.

I have not as yet had time to give a fair trial to the coil with a battery of greater power than that of three 4-inch cells. With one cell in which the zinc plate was 4 inches by 8, I got sparks $8\frac{1}{4}$ inches long when the plate connected with the negative end was only 4 inches in diameter. Had I known at the time that with a 12-inch plate the spark is $1\frac{1}{4}$ inch longer than with a 4-inch one, the sparks with the single cell 4×8 would have been $9\frac{1}{2}$ inches long. I intend to try the coil as soon as convenient with a battery of twelve 6-inch cells, and six cells 4 inches by 8.

St. Patrick's College, Maynooth,
May 13, 1863.

LVII. *On Celestial Dynamics.* By Dr. J. R. Mayer.

[Concluded from p. 409.]

IX. *The Heat of the Interior of the Earth.*

WITHOUT doubt there was once a time when our globe had not assumed its present magnitude. According to this, by aid of this simple assumption, the origin of our planet may be reduced to the union of once separated masses.

To the mechanical combinations of masses of the second order, with masses of the second and third order, &c., the same laws as those enunciated for the sun apply. The collision of such masses must always generate an amount of heat proportional to the squares of their velocities, or to their mechanical effect.

Although we are not in a position to affirm anything certain respecting the primordial conditions under which the constituent parts of the earth existed, it is nevertheless of the greatest interest to estimate the quantities of heat generated by the collision and combination of these parts by a standard based on the simplest assumptions.

Accordingly we shall consider for the present the earth to have been formed by the union of two parts, which obtained their relative motions by their mutual attraction only. Let the whole mass of the present earth, expressed in kilogrammes, be T, and the masses of the two portions $T-x$ and x. The ratio of these two quantities may be imagined to assume various

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nitric acid diluted with its own volume of water. Into the nitric acid were poured alternately small quantities of a solution of nitrate of silver and of hydrochloric acid, the object being to cause the chloride of silver to form in a minutely divided state, so as to produce a milky liquid, into the interior of which the brilliant converging cone of light might pass, and the currents generated in the flask by the heat, might drift all the chloride successively through the light. The chloride, if otherwise exposed to the sun, merely blackens upon the surface, the interior parts undergoing no change; this difficulty I hoped therefore to avoid. The burning-glass promptly brings on a decomposition of the salt, evolving on the one hand chlorine, and disengaging a metal on the other. In one experiment the exposure lasted from 11 A.M. to 1 P.M.; it was therefore equal to a continuous midday sun of seventy-two hours. The metal was disengaged very well. But what is it? It cannot be silver, since nitric acid has no action upon it. It burnished in an agate mortar, but its reflexion is not like the reflexion of silver: it is yellower. The light must therefore have so transmuted the original silver as to enable it to exist in the presence of nitric acid. In 1837 I published some experiments on the nature of this decomposition in the Journal of the Franklin Institute.

Though this experiment, and several modifications of it which I might relate, fail to establish any permanent change in the metal under trial in the sense of an actual transmutation, it does not follow that we should despair of a final success. It is not likely that Nature has made fifty elementary substances of a metallic form, many of them so closely resembling one another as to be with difficulty distinguished; moreover, chlorine and other elementary substances can be changed by the sunlight in some respects permanently; and if silver has not thus far been transmuted into a more noble metal, as platinum or gold, it has at all events been made transiently into a something which is not silver. Those who will reflect a little on the matter, cannot fail to observe that the sun-rays really possess many of the powers once fabulously imputed to the powder of projection and the philosopher's stone.

XXXVIII. *On the Induction Apparatus.* *By the* Rev. N. J. Callan, *D.D., Professor of Natural Philosophy in the Roman Catholic College, Maynooth**.

It is now more than twenty years since I discovered the method of making the induction coil, or a coil by which an electric current of enormous intensity may be produced with the

* Communicated by the Author.

aid of a single galvanic cell,—a coil which is now to be used for working the Atlantic Telegraph. Mr. Faraday was the first who developed the laws of electrical induction; but he did not discover the method of making a coil by which a current of very great intensity may be obtained by means of a very small battery. This was first discovered in Maynooth College in 1836. In the summer of 1837, I sent the late Mr. Sturgeon a small coil which he exhibited at a meeting of the Electrical Society in London, and from which he gave shocks to several of the members. After the meeting, I received a letter of thanks from him, in which he described the astonishment of those who experienced the extraordinary power of the coil. This was the first induction coil of great power ever seen outside the College of Maynooth. The first notice of the discovery of the coil is found in a paper of mine published in the London Philosophical Magazine for December 1836. In 1836 and 1837 I also discovered that the intensity of the current induced in the coil increased with the number of cells employed, and that a shock may be got from the coil at the moment of making as well as of breaking connexion with the battery. In April 1837 I published, in Sturgeon's 'Annals of Electricity,' a description of an instrument which I devised for producing a rapid succession of electrical currents in the coil by rapidly making and breaking communication with the battery. This, as Mr. Bachhoffner says in one of his papers published in Sturgeon's 'Annals,' was the first contact-breaker ever made. Thus, before April 1837 I had completed the coil as a machine for producing a regular supply of electricity. From 1837 till the end of 1854 my attention was directed to other matters. Since the beginning of 1855, I made a long series of experiments on the various parts of the induction coil and apparatus. Although my experiments are not yet finished, I thought it better to lay the results already obtained before the British Association*.

The following are the results of my experiments:—First, a method of getting a shock directly from the armature of a magnet at the moment of its demagnetization; secondly, the discovery of what I believe to be a new fact or law connected with the action of iron on a battery by which it is magnetized, viz. that if iron be put into a coil of covered wire, the ends of which are connected with a battery, the quantity of electricity flowing from the same battery through another coil connected with it will be considerably greater when the first coil is nearly filled with iron than when there is little or no iron in it; thirdly, a

* This paper was read in Section A. (on Mathematics and Physics) at the late meeting of the British Association in Dublin. The paper being hastily written, some things were omitted which are here supplied.

form of core which has five advantages over the cores in common use, which will enable us to get intensity and quantity currents, and may therefore answer for the Atlantic Telegraph and for the electric light; fourthly, an improved method of insulating the secondary coil; fifthly, a contact-breaker in which the striking parts are copper, and which acts as well as if they were platina; sixthly, an explanation of the action of the condenser, which appears to me more satisfactory than any other I have seen; lastly, some new facts regarding the condenser, and an improved method of making it.

The first result is a means of obtaining, not from a coil surrounding the armature of a magnet, but from the armature itself, a voltaic current capable of giving a shock. This result is obtained by making a coil of fine insulated iron wire, and an electro-magnet of such a form that the coil will fit between its poles. The iron coil is then the armature of the magnet. If the helix of the electro-magnet be connected with a battery, the iron becomes magnetized; and on account of its proximity to the magnetized iron, the coil of iron wire, or the armature of the electro-magnet, will be also magnetized, and will lose its magnetism when the connexion between the battery and electro-magnet is broken, or when the electro-magnet is demagnetized. If, at the moment the iron coil loses its magnetism, the ends of it be held in the hands, a shock will be felt. If the ends of the iron coil be connected with a delicate galvanometer, the needle will be deflected at the moment the coil is magnetized by the electro-magnet. Hence at the moment of magnetization or demagnetization, an electric current is produced in each section of the iron at right angles to its magnetic axis. From this, two inferences may be drawn,—first, that if for the copper coils used in magnetic telegraphs, coils of iron wire were substituted, electrical currents of greater intensity might be obtained; secondly, that if iron wire were used in the secondary coil of induction coils, the intensity of the secondary currents would be increased.

Here I shall take occasion to explain the causes which produce the secondary current in the induction coil. I believe that this current is the result of the combined action of three inductive forces; one arising from the sudden cessation or destruction of the magnetism of the core, the second from the cessation of the magnetism of the primary coil, and the third from the destruction of the magnetism of the secondary coil at the moment the connexion between the battery and primary coil is broken. This supposes, first, that as long as the primary coil is connected with the battery, magnetic power is given, not only to the iron core, but also to the primary and secondary coils; and secondly, that in each of them, at the moment of losing its magnetism, an electric

current is produced in each of them as well as in all contiguous conductors. Both, I think, may be satisfactorily proved. First, every one knows that the iron core is magnetized by the primary current. Secondly, the primary coil itself is a magnet as long as it is connected with the battery; for every wire or conductor through which a voltaic current flows has magnetic properties: one of its sides will attract the north pole of a magnetic needle, and the opposite will attract the south pole; so that if the wire be placed over the needle at rest, the latter will be deflected from the magnetic meridian. The wire, or conductor of a galvanic current has its magnetic poles, not at its extremities, but at its opposite sides; so that were the wire divided into two halves along its length, one half would be a north and the other a south magnetic pole. The magnetic axis of such a wire is one of its diameters, or a line joining its opposite sides. Thirdly, the secondary coil is a magnet when the primary coil is connected with the battery. This is evident when the secondary coil is made of iron wire; for the primary current magnetizes iron by which it is surrounded as well as iron enclosed within it: it induces in each section of the surrounding as well as of the enclosed iron, an electrical current which magnetizes the iron. I have found by experiment that iron outside the primary coil is not so strongly magnetized as iron enclosed within it. When, as is commonly the case, the secondary coil is made of copper wire, it is also a magnet; for the primary current induces an electrical current in each spiral of the secondary coil of copper, as well as in each section of the iron core. This current magnetizes each spiral of the copper coil, and makes the whole coil a magnet at the moment the primary coil is connected with the battery. Now we must suppose, that as the primary current, whilst it continues to flow, maintains in the iron core the magnetic power produced by the currents induced in each section of the iron at the moment the primary coil is connected with the battery, although these currents last but an instant, so also the same primary current will maintain in each of the spirals of the copper coil the magnetism given to them by the currents induced in them at the moment the battery connexion is made. There is no reason why the continuance of the primary current should not maintain its first effect in the copper spirals as well as in the iron, since the first effect is the same in both, viz. the magnetization of both. Hence, when the primary wire of an induction coil is connected with a battery, the secondary coil is always a magnet, as well as the core and primary coil; and therefore in every induction coil we have three magnets so long as its primary coil is connected with a voltaic battery; and the three lose their magnetism the moment the battery communication is

broken. Now in every magnet, at the moment of the cessation of its magnetism, an electric current is produced in a direction at right angles to the magnetic axis, in the magnet itself and in all contiguous bodies. First, it has been already shown that at the moment iron loses its magnetic power, an electric current is produced in each section of it in a direction perpendicular to its magnetic axis. By the laws of induction, these currents induce parallel ones in every contiguous conductor. Secondly, when a current flowing from a battery through a copper wire ceases, the wire loses its magnetism; and it is found by experiment, that at the moment of losing its magnetism, an opposite electrical current is produced in the whole length of the wire, or in a direction at right angles to its magnetic axis. Hence, because in every induction coil excited by a battery there are three magnets, viz. the core, the primary and secondary coils, having a common axis, and because at the moment the connexion with the battery is broken the three lose their magnetic power, an electrical current is produced in each section of each of the magnets in a direction perpendicular to their common axis; and these currents in each magnet induce electrical currents in the other two. Therefore, when the connexion with the battery is broken, a current is produced in the secondary coil, which is the result of the combined action of three inductive forces arising from the suspension of the magnetism of the core, of the primary and of the secondary coil. When the secondary coil is made of iron wire, the magnetic power it will receive from the primary current, and from the magnetic inductive force of the core, will be far greater than if it be made of copper wire; and therefore the intensity of the secondary current in a coil of iron wire must be much greater than that of the secondary current in a coil of copper wire. I showed, at the late meeting of the British Association in Dublin, an induction coil in which the secondary wire was of iron: its length was about 21,000 feet, and its thickness about the $\frac{1}{100}$dth of an inch. With a single cell, 6 inches by 4, and without a condenser, this coil gave sparks half an inch long. Should a condenser of the proper size increase the length of the sparks, as it does in Mr. Gassiot's great coil, in a thirtyfold ratio, my coil ought to give sparks 15 inches long with a single cell. I have not yet tried it with a condenser: I made two large condensers, in which, when both were united, the acting surface of each plate exceeded 600 square feet. After being used for some time, the insulation of the plates gave way, and the action of the condenser became feeble, and once ceased altogether. I intend to reconstruct both condensers as soon as possible, and to try their effect on the coil, on which I have, since the meeting of the Association, coiled about 28,000 feet more of fine iron wire, so

that at present the length of the secondary coil is nearly 50,000 feet. Since the increased length of wire was put on the coil, I have got from it, with a single cell, 6 inches by 4, and without a condenser, sparks $\frac{15}{16}$ths of an inch in length. I expect that with the same battery it will give sparks at least an inch long without a condenser. This is, I believe, the most powerful coil ever made.

The second result is, that if a bundle of iron wire be put into a coil of insulated thick copper wire connected with a battery, the quantity of electricity which will flow through another coil in contact with the same battery, will be considerably greater when the iron wires are in the first coil than when they are altogether or partly removed. This I found by using a contact-breaker worked by an electro-magnet, the helix of which was connected with the same battery by which an induction coil was excited. In trying the effect of the induction coil without an iron core in its primary coil, I found that the action of the electro-magnet of the contact-breaker was slow and feeble. When a few wires were put into the primary coil, the action of the contact-breaker was sensibly increased; and when the primary coil was filled or nearly filled with wire, the attraction of the electro-magnet became considerably stronger, and consequently the voltaic current flowing round it must have been considerably increased. Since the core of the induction coil increases the quantity of electricity flowing from the battery through the helix of the electro-magnet, we must suppose that the iron of the magnet reciprocally increases the quantity of electricity transmitted through the primary coil, and that therefore little or no battery power is lost by using an electro-magnet for making and breaking contact, instead of the magnetized core of the coil. Hence it appears also to follow, that a secondary current of greater intensity may be got with a battery of given power from a great number of small coils than from one large one, in which the conducting power of the primary coil is equal to the sum of the conducting powers of the primary wires of all the small coils; for the magnetic power of the core of each of the small coils will be increased by the magnetism of the cores of the others.

The third result is a form of core which has five advantages over all the cores in common use, and which may enable us to get electrical currents having at the same time great intensity and considerable quantity, and may therefore be very useful for working the Atlantic Telegraph, and for producing the electric light. In my experiments on the core, I have used cores of six different forms, and varying in weight from one pound to two hundred and a half of iron wire. I have used, first, a core of uninsulated iron wire coiled on an iron bar; secondly, the ordi-

nary bundle of iron wires; thirdly, an elliptical or flat bundle of wires; fourthly, a coil of covered iron wire; fifthly, a core consisting of a coil of insulated iron wire and of a bundle of iron wire; lastly, a core consisting of two concentric coils of insulated iron wire, one made of fine, the other of thick wire.

When the uninsulated iron wire coiled on a bar of iron was employed as a core, the spark produced by the secondary coil was less in length and brightness than when the iron bar alone was used; because a complete circuit was formed between some of the spirals and those above them, whilst the other spirals were insulated from each other by the oxide of iron on the surface of the wire.

The elliptical or flat bundle of wire receives from a given voltaic current flowing through a primary coil made of wire of given length and thickness, greater magnetic intensity than a cylindrical bundle does; because when the length of the circumference of the two bundles is the same, a section of the former is smaller, and contains less iron than a section of the latter. Therefore, if the two coils be connected with the same battery, the same quantity of electricity will flow through both; and the quantity of iron in the flat or elliptical one being less than in the cylindrical one, it will be more intensely magnetized.

I find that all cores consisting of bundles of parallel wires have five defects. First, in each section of every wire in such cores an electrical current is induced by the primary current, and all those currents may return to the points where they originated; or there is a complete circuit for them, which is found to diminish the intensity of the secondary current. Some have imagined that by insulating the wires of the core from each other, they have prevented all complete circuits. But these persons seem to have forgotten, or not to have adverted to the fact, that when the wires of the coil are insulated from each other, the primary current induces an electrical current in each section of every wire.

The second defect consists in this, that the currents induced in each section of every wire are opposed by those in the corresponding sections of all the adjoining wires; and thus the magnetic power which the primary current is capable of producing in the core is greatly diminished, and is less than it would be if all the wires were in close contact with each other; and consequently the intensity of the secondary current is diminished.

The third defect is, that the immense quantity of electricity set in motion by the primary current in all the sections of each wire in the core is lost: it remains within the core, and cannot be used for producing any electrical effect.

The fourth defect is, that we cannot ascertain the effect

which a condenser applied to the primary coil has on these currents.

The fifth defect is, that we cannot apply a Leyden jar or any condenser to the currents themselves.

I have found that a core consisting of a coil of insulated or covered iron wire is free from all these defects. In such a core there is no complete circuit for any current in any section of the iron: for the electrical currents produced by the primary current in the sections of an enclosed iron coil move in the directions of the spirals of the coil; and since no spiral returns to itself, no current can return to the point where it originated. Neither does the current in any spiral of the coil oppose those in the adjoining spirals; for the currents in all the spirals flow in the same direction, or in the direction of the primary current. Thirdly, since all the currents in the spirals of the iron coil flow in the same direction from the beginning to the end of the coil, they must unite and form one current, having an intensity equal to the sum of their intensities. This I have proved by using a coil of very fine insulated iron wire, about 10,000 feet in length, as the core of a copper coil. When the connexion between the ends of the copper coil and a single cell was broken, sparks about one-twelfth of an inch passed between the ends of the thin iron wire without using a condenser. Fourthly, by connecting the primary coil with a condenser, I have found that the intensity of the current in the core is increased as it is in the current of the secondary coil. Fifthly, by connecting the ends of the core or iron coil with a Leyden jar, the length of the spark is diminished and its brightness increased. The effect of the condenser on the currents in the core may assist us in understanding the action of the condenser, which has not yet been satisfactorily explained.

A core consisting of a coil of insulated iron wire, has not only the advantages of being free from the five defects to which all the cores in common use are subject, but it will also enable us to get electrical currents having at the same time great intensity and considerable quantity, and may therefore be very advantageous for working the Atlantic Telegraph, and for producing the electric light. If we make a core of thirty covered iron wires, each one-eighth of an inch thick and 100 feet long, and wind over the iron coil a covered copper wire one-fourth of an inch thick, we can, with the aid of two cells and a suitable condenser, obtain thirty electrical currents, each having a considerable quantity of electricity, because the wires are short and thick, and an intensity greater than that which is required for the electric light. Sixty covered iron wires, of the same length and thickness as those in the core, may be rolled on the copper coil. Another coil of cop-

per wire, one-fourth of an inch thick, may be put over the second iron one, and over this copper coil we may wind sixty or eighty covered iron wires, each 100 feet long and one-eighth of an inch thick. Then the innermost iron coil will be the core of the first copper one; the second iron coil will be the secondary coil of the first copper coil, and the core of the second; the third iron coil will be the secondary coil of the second copper coil. If the copper wires be connected with a battery of six cells, each about 5 inches square, and a condenser of sufficient size, an enormous magnetic power will be given to the 150 or 170 wires of the iron coils; and consequently 150 or 170 electric currents of considerable quantity and intensity will be produced as often as the connexion between the copper wires and the battery is broken. If necessary, the number of iron coils, and therefore the number of electric currents, may be increased. Mr. Shephard has got a brilliant electric light from eighty electric currents produced in coils of copper wire on the armatures of permanent magnets. I think that 150 currents produced by the coil I have described would far exceed in quantity and intensity the eighty currents obtained from Mr. Shephard's machine.

The electric light may perhaps be produced by several coils, like the one I showed at the meeting of the Association, and which has given sparks the $\frac{15}{16}$th of an inch, with one cell and without a condenser. The secondary coil is divided into four parts, each of which will give sparks about a quarter of an inch. I intend to make four or five other coils of equal power, and to divide the secondary coil of each into six or eight parts. The ends of the wire of each part will be left projecting from the coil. Thus in the five or six coils there will be between thirty and forty small secondary coils, each containing about 8000 or 10,000 feet of fine iron wire. Each of these secondary coils will give sparks at least one-eighth of an inch, with a battery of five or six cells and without a condenser. With a good condenser we may fairly expect that each will give sparks nearly 2 inches in length. Thus with a battery of five or six cells I think I shall have between thirty and forty currents, each capable of passing through about 2 inches of air. If the opposite ends of the thirty or forty small coils be connected with the opposite coatings of several large Leyden jars, and the sparks be passed between two coke-points, a brilliant light may be produced. Besides the coil which I have described, and which was divided into four parts, I made another which was 40 inches long, was divided into nine parts, and in which there were at least 70,000 feet of fine iron wire. Unfortunately, the secondary coil was seriously injured before I was able to make a single trial of its power. In dividing the two coils into several parts, I had three objects

in view. First, to secure better insulation. The division of the secondary coil for the purpose of preventing the passage of sparks from one layer of the coil to the layer above or below it, was first recommended by Professor Poggendorff. Although this mode of preventing sparks within the coil occurred to myself before I saw his excellent paper on the induction apparatus, I was doubtful whether it would be of use, until I tried it in the last coil I made. My second object in dividing the secondary coil into parts, was to try the combined effect of the currents produced in each part by connecting the beginnings of all the parts with one coke-point, and all the ends with another. My third object was to try the effect of a Leyden jar connected with each part of the secondary wire, as well on the sparks produced by the part itself, as on the sparks produced by the whole secondary coil.

In order to get currents of considerable quantity, and at the same time of very great intensity, the core and secondary coil should be one continuous wire, about one-eighth of an inch thick, and the end of the core should be connected with the beginning of the secondary coil. I made a flat coil of covered iron wire one-eighth of an inch thick. The length of the coil was about 18 inches, its breadth 14, and its thickness between 4 and 5 inches. The length of the wire was about 2000 feet. On this iron coil I wound 150 feet of copper wire nearly one-fourth of an inch thick. By connecting the ends of the copper wire with a battery of two or three 4-inch cells, and a condenser in which the surface of each plate was 400 square feet, sparks about the twentieth of an inch would be made to pass between the terminals of the iron core. I have reason to think that had the condenser been only one-third or one-fourth of the size, the sparks would have been longer. When the ends of the iron core were connected with a condenser in which the acting surface of each plate was about fifty square feet, and in which the plates were insulated from each other by waterproof gutta-percha cloth, the current passed from one plate of the condenser to the other as freely as if they were connected by a good conductor. When the terminals were connected with three large Leyden jars, the brightness of the spark was increased, whilst its length scarcely suffered any diminution. I intended, but had not time, to coil over the copper wire another iron one of great length, and the same thickness as the one in the core, and to unite both together. Had I been able to do so, the combined currents of the core and secondary coil would form one of enormous intensity and considerable quantity. Two coils of this kind, each having a bar of iron in the inner iron coil, and having the ends of the iron bars connected by iron armatures, in the same way as in Mr. White-

house's coils, would, I think, answer better than his for the Atlantic Telegraph.

It appears to me that Mr. Whitehouse's coils admit of three important improvements. First, they may be greatly improved in the core by substituting for his secondary coil of copper wire a coil of covered iron wire of the same length and thickness. The iron wire would be intensely magnetized by the primary current, and by the inductive magnetic power of the enclosed iron bar; and in losing its magnetism at the moment the battery connexion is broken, a current will be induced in it of far greater intensity than that of the secondary current in Mr. Whitehouse's coil. Mr. Whitehouse's object in connecting the ends of one core with the ends of another by iron armatures, is to prevent the rapid suspension of the magnetic power of the cores at the moment the connexion between the battery and primary coil is broken. By causing the cores to lose their magnetism gradually, a series of currents corresponding to the successive diminutions of magnetic power is induced in the secondary coil: this series of currents has the effect of a continuous current, which is found to be of use in working the telegraph. The same object may be attained by using a core consisting of an iron bar and a coil of insulated iron wire. The iron bars may be connected by iron armatures extending over the ends of the iron coils, but separated from them by a piece of gutta-percha about the one-fortieth of an inch in thickness. Mr. Whitehouse's object might perhaps be attained still better by connecting the cores of every two coils, by six or seven, or a greater number of armatures. This may be done by brazing or otherwise fastening to the iron bar in each coil, plates of iron about a quarter or three-eighths of an inch thick, and sufficiently large to project an inch or two beyond the iron coil of the core. A small piece should be cut out of each plate, that the primary wire may pass from one side of the plate to the other. The corresponding plates fastened to the two iron bars may be connected by a plate of iron. Thus the two iron bars will have as many armatures as iron plates, and the magnetic power of the core will be retained longer than if there be only two armatures, and consequently the series of induced currents will continue for a longer time. Secondly, a great improvement may be made in the primary coil. Mr. Whitehouse's primary coil consists of twenty-four copper wires, No. 14, or about the $\frac{1}{11}$th of an inch thick, and 100 feet long. Now if the primary coil were made of copper wire of the same length, and nearly half an inch thick, it would conduct as much electricity as the twenty-four wires used by Mr. Whitehouse, and would produce greater magnetic power in the core, because the electricity flowing in the thick wire would be nearer to the core than

the electricity flowing through the twenty-four thin wires. A third improvement may be made by winding over the primary coil an insulated iron or copper wire of the same length and thickness as the wire in the core, or of greater length, and uniting the end of the coil in the core with the beginning of the coil outside the primary coil. Such a coil would produce with a given battery a current of far greater intensity than that which would be produced by one of Mr. Whitehouse's coils, or a current of equal intensity with a much smaller battery. It appears to me, then, that the use of coils such as I have described would be greatly to the advantage of the Atlantic Company, or any company having a very long telegraphic line.

The fifth form of core which I used consisted partly of a coil of insulated iron wire, and partly of a bundle of iron wire. In one core of this form the iron wire of the coil was about the $\frac{1}{100}$dth of an inch, in another it was one-eighth of an inch thick. From the part of the core which consisted of iron wire $\frac{1}{100}$dth of an inch thick, I got sparks a quarter of an inch with a single cell and without a condenser. The length of wire in this coil was about 15,000 feet.

The sixth form of core which I used consisted of two concentric coils of insulated iron wire: one of very fine, the other of thick wire. The coil of thick wire should be enclosed within the coil of fine wire, and should be nearly 2 or 3 inches in diameter, especially when the primary coil is made of thick wire. In making coils of thick iron wire, great care is necessary, for in such wire there are cracks or flaws. At these cracks there are sometimes sharp points, which cut the covering of a spiral in an adjoining layer, and thus make a complete circuit, which is most injurious to the intensity of all the currents induced in the various parts of the coil. It is necessary to know that the complete circuit which diminishes the intensity of the secondary current in the greatest degree, is that which is made by connecting the ends of a coil of thick wire. I have not had time to determine which of the forms of core I have used induces the most intense current in the secondary coil, or which of them makes the condenser act with the greatest effect. I once used for the core a bundle of wires, 9 inches in diameter and 26 inches long. The weight of the core exceeded two hundred and a half pounds. This core acted so badly, as to convince me that anyone who wishes to obtain currents of very great intensity, or very long sparks, should never employ cores of very large diameter.

The fourth result is an improved method of insulation for the secondary coil. In this mode the insulation is imperfect where imperfect insulation is sufficient, and perfect where such insu-

lation is required, and consequently each spiral is brought nearer to the core, to the primary coil, and to the other spirals of the secondary coil, than in the ordinary manner of insulation, in which the parts of each layer for which very little insulation is required are as well insulated from the layer above and below it as the parts which require the best insulation. My mode of insulation differs from the ordinary one in two respects:—First, in the insulation of each spiral from the adjoining ones in the same layer; secondly, in the insulation of the spirals of every layer from the contiguous spirals of the layer above it. I do not cover the fine wire with thread of any kind; but I coat it with a very thin film of varnish by drawing it through melted rosin and bees-wax. I draw it through the hot varnish by winding it on the coil at the distance of about 25 feet from the stove by which the varnish is heated; I have found that at this distance the varnish is cool and hard, even when the wire is drawn through it at the rate of 8000 feet in the hour. Thus in this mode of insulating the fine wire, a coil may be made in a comparatively short time. The insulation is sufficient, because the difference between the intensity of any spiral and the adjoining ones of the same layer is indefinitely small. On every inch of each layer I can put eighty or eighty-two spirals of wire $\frac{1}{100}$dth of an inch thick. My mode of insulating the spirals of each layer from those of the layer above or below it, differs also from the way in which they are insulated by others. In the common mode of insulation, if, as in Mr. Gassiot's great coil, five thicknesses of gutta-percha, or of any other insulating substance, be thought necessary in order to insulate the extreme spirals of any layer from those of the layer below it, five thicknesses of the insulating substance are put between the whole length of every two adjoining layers; so that if there be twenty layers along with the first, there will be 100 thicknesses of the insulating substance. But, in my mode of insulation, there would, in such a case, be only sixty. In order to render my mode of insulation intelligible, I shall explain how the first layer of spirals is insulated from the second, and the second from the third. Every other layer, such as the third, fifth, seventh, &c. represented by an odd number, will be insulated from the one above it, in the same way as the first is insulated from the second; and every layer, such as the fourth, sixth, eighth, &c. represented by an even number, will be insulated from the one above it, in the same way as the second is from the third. In insulating the first layer from the second, when five thicknesses of the insulating substance to be used are deemed necessary for the insulation of the last spirals of the second layer from the first spirals of the first (there the difference of intensity

is greatest), I divide the length of the layer into five equal parts. I then put one thickness of the insulating substance (let us suppose it to be what I use, viz. the paper employed for copper-plate engravings saturated with a solution of gutta-percha in oil) on the entire length of the first layer, and then roll the fine wire on one fifth of the layer. I next cover the whole length of the coil with another thickness of prepared paper, and coil the fine wire on the second fifth of the layer. I then put on a third thickness of paper, and wind the wire on the third fifth of the coil. I then put on another thickness of paper, and coil the wire on the fourth fifth, and so on. Then between the first fifth of the second layer and the spirals below it in the first, there is one thickness of paper; and one will insulate them as well as five will insulate the whole length of the two layers from each other. Between the second fifth of the second layer and the part of the first layer below it, there are two thicknesses of paper, and they will sufficiently insulate these two parts from each other. In the same way the third is insulated by three thicknesses, the fourth by four, and the last by five thicknesses of paper: thus the five parts of the coil are as well insulated from each other as if there were five thicknesses between the entire length of the two layers. To insulate the second layer from the third, as well as the first is insulated from the second, only one thickness of paper is necessary; for by putting a single thickness of paper on the second layer, the first fifth is covered by one, the second by two, the third by three, the fourth by four, and the last by five thicknesses of paper. Hence to insulate any two layers, only six thicknesses of the insulating substance are necessary, or three for the insulation of each layer; and therefore to insulate twenty layers, only sixty thicknesses of the insulating substance to be used are required. Thus in my mode of insulation, every spiral in the secondary coil is brought nearer to all the contiguous spirals and to the primary coil and core, than in the ordinary method of insulation; and consequently the inductive power of the core and of the primary coil on the secondary one, as well as the inductive power of the spirals of the secondary coil on each other, must produce a secondary current of far greater intensity in mine than in the common mode of insulation. The coil which was shown at the meeting of the British Association was insulated in the manner just explained. This coil and the contact-breaker, which will be presently described, were seen at work by Mr. Gassiot, Dr. Robinson, M. Foucault, Professor Rogers, and other members of the Association. Mr. Gassiot was so much pleased with their action and construction, that he ordered from Mr. Yeates, an optician in Dublin, a contact-breaker and two secondary coils like mine. In

each of these secondary coils there will be nearly 60,000 feet of iron wire about the $\frac{1}{100}$dth of an inch thick.

The fifth result is a contact-breaker in which the striking parts are copper, and which act as well as if they were platina. The contact breaker consists, first, of a small electro-magnet; secondly, of its armature screwed to a board moveable on a hinge, and having attached to it a spring connected with the vibrating piece of copper; thirdly, of a spring for pressing the striking pieces together; and of a trough containing oil, in which these pieces are always immersed. By means of the spring attached to the board to which the armature is fastened, the armature is brought within the most convenient distance from the small electro-magnet. The spring presses the striking pieces together with the greatest force the electro-magnet is capable of overcoming, and the pressure is exerted immediately over the points of contact. The oil prevents in some measure the oxidation of the copper, and serves to stop the battery current more quickly; for as soon as the pieces of copper are separated, the oil rushes in between them, and being a non-conductor, instantly stops the galvanic current from the battery. In the first contact-breaker which I made of this kind, there were two vibrating pieces, one of platina, the other of copper; the former struck against another piece of platina, the latter against a piece of copper: the copper was immersed in oil. By means of two screws, both might be made to make and break contact together, or I could cause either to make and break contact. By first causing the platina, and afterwards the copper, to make and break contact, I found that the copper acted as well as the platina. In the contact-breaker which I showed at the meeting in Dublin, there were three vibrating pieces of copper, each about three-eighths of an inch thick. M. Foucault thinks that the contact will be made and broken as well by one as by several vibrating pieces. Though that should be the case, the addition of two other pieces will not be useless; for the three may be immersed in different fluids, and thus we can discover the fluid in which contact may be made and broken with the greatest advantage.

The sixth result is a more satisfactory explanation of the condenser. In order to understand the action of the condenser, we must examine the electrical state of the primary coil at the moment its connexion with the battery is broken, and the effect which this state has on the core and secondary current. At the moment the connexion between the battery and primary coil is broken, the electricity which it received from the battery continues to flow to the end of the coil to which it was moving; but being no longer urged forward by the battery, its velocity

is, however, the large induction coil, which may be regarded as the completion of Dr. Callan's labours. Although constructed 30 years ago, it is still one of the largest coils in existence. The representation of it in Fig. 13 is from a photograph recently made. The core is a cylindrical bundle of annealed iron wires 42in. in length, and 3·5in. in diameter. The thickness of each wire is $\frac{3}{16}$in. The primary coil is a copper wire, ·25in. in diameter, covered with cotton thread, and wound in three layers. For insulation the primary coil is covered with several layers of thin sheet gutta-percha, cemented by a paste, formed by dissolving gutta-percha, resin, and wax in boiling oil. The secondary coil is of *iron* wire ·01in. diameter, and consists of three separate coils or rings. The inner diameter of each coil or ring is 5·75in., and the outer diameter is 21in. Two of the rings are 3in. in thickness, and one is 4in. The rings are so arranged on the primary coil as to divide its entire length into four equal parts, the planes of the rings being perpendicular to the axis of the coil. In each ring both ends of the wire are left projecting, so that the separate coils can be joined in series or in parallel. The contact breaker is an automatic mercury

break, worked from one extremity of the core. Two condensers, so arranged that they can be used together or separately, serve to reduce the spark at the break. With six cells of the Maynooth or cast iron battery, sparks 15in. long in air can be still obtained, the rings or secondary coils being joined in series. Prof. Gerald Molloy states* that the construction of this coil was commenced by Dr. Callan some years before his death, which occurred in January, 1864, and that it was then left in an unfinished condition. It was probably his intention to add more secondary coils to it. It remained one of the most powerful coils down to the time of the construction of Mr. Apps' large coils for the Polytechnic and for Mr. Spottiswoode. A

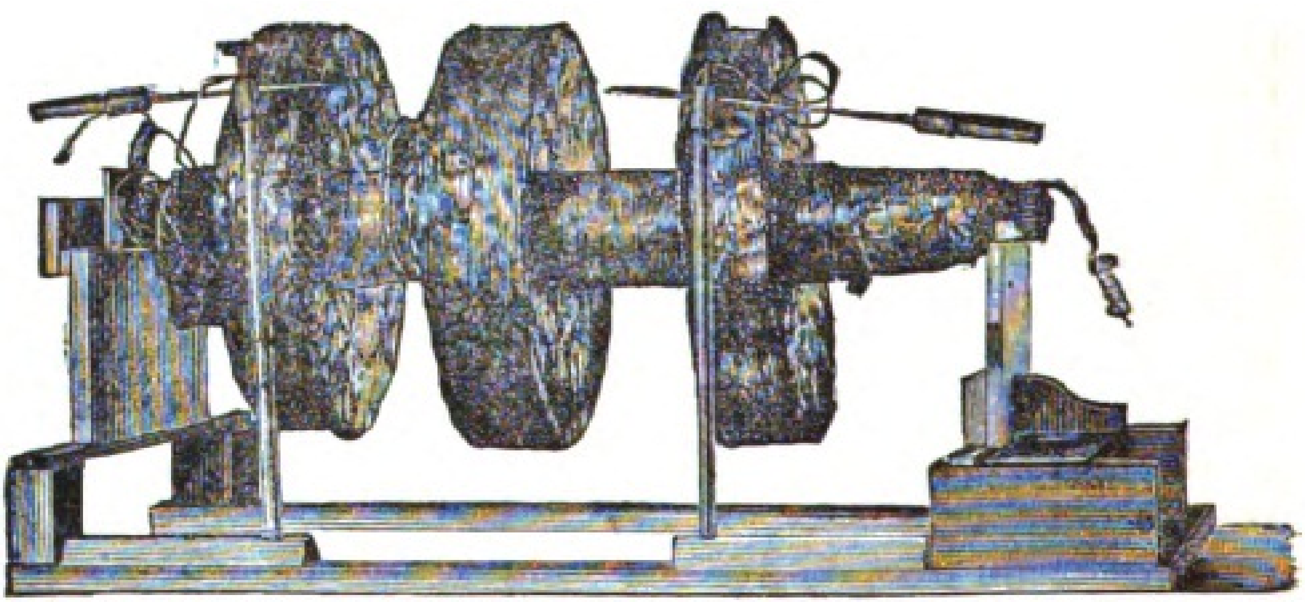

FIG. 13.—Dr. Callan's Large Induction Coil completed in 1863. Still preserved at Maynooth College.

long Paper by Dr. Callan on the induction apparatus, describing his latest researches, is printed in the *Philosophical Magazine* for 1857, Vol. XIV., 4th series, p. 323. This Paper is full of valuable suggestions and facts.

A description of the large induction coil, and experiments with it, will be found in the *Philosophical Magazine* for June, 1863 (Vol. XXV., Series 5, p. 413). Dr. Callan says that about three years and a-half before the date of writing he made an induction coil of considerable power. The secondary coil was of iron wire, No. 34 gauge, and consisted of three parts, two of which were each about two and a-half inches, and the third

* See *Electrician*, February 13, 1891, Vol. XXVI., p. 465.

three inches long. The entire length of the secondary coil was about eight inches, and it contained 150,000ft. of secondary wire. He used thin sheet gutta-percha in insulating the layers of wire. The primary coil was nearly three feet long, and the soft iron wire core three feet six inches long. This long primary coil was probably intended to be overlaid with more secondary wire, and as left at Dr. Callan's death the coil was incomplete. With three cells of the Maynooth battery this coil would give sparks 15in. in length.

Dr. Callan discovered that an increase in length in the spark is produced by connecting a large plate of any metal to the negative terminal of the coil, and that, in order to get the longest spark, the outer end of the secondary coil should be positive, and the inner end the negative. He states (see *Philosophical Magazine*, June, 1863) that when a pointed wire is connected with the positive end of the secondary a plate connected with the negative end lengthens the spark considerably, but when the point is connected to the negative end and the plate to the positive one the sparks are much shorter. Sparks 15in. long, when the first arrangement is made, are reduced to 11in. with the second. Sparks did not pass at all between positive plate and negative point until the plate was brought within eight and a-half inches from the point.

A ball, three inches in diameter, connected to the positive terminal shortens the spark as much as a 12-in. plate. He noted also that sparks from a positive point to a negative plate never went to the circumference of the plate, and scarcely ever struck the plate at a greater distance from the centre than three inches. But sparks between a negative point and positive plate always went to the circumference until the plate was brought to within two and a-half or three inches of the point; even when a rectangular plate 20in. by 28in. was used as the positive terminal the sparks flew to the edge of the plate.

§ 9. **C. G. Page's Researches in Electro-Magnetism.**—Very nearly at the same time that Prof. Callan, of Maynooth, was assiduously engaged in England in experimental inquiries on the induction coil, Dr. C. G. Page, at Salem and at Washington, in the United States, prosecuted with the greatest zeal and